NUCLIDE CORPORATION

THE ANALYSIS OF THE
LUNAR ATMOSPHERE
BY A MASS SPECTROSCOPE

By L. F. Herzog and S. R. Gryczuk

MASS SPECTROSCOPY

VACUUM TECHNOLOGY

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RESEARCH AND DEVELOPMENT

ANALYTICAL SERVICES

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September 1968

Period of Research

August 4, 1966 through March 31, 1968

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ABSTRACT

This report describes the work carried out during an 18 month period from August 4, 1966 to March 31, 1968 to investigate the potential of mass spectrometry to perform the analysis of the lunar atmosphere as part of the ALSEP program.

In a study conducted in 1965-1966, the time-of-flight (TOF) mass spectrometer was selected over the monopole for performing an in-flight analysis while passing through the lunar atmosphere on a collision course with the surface. While this possibility still exists, in the present study, it was assumed that the instrument would be set in place on the lunar surface by an astronaut.

Conducting the experiment in this manner on the Moon will make it possible to improve in the performance of the TOF, compared to the laboratory prototype, as the source-to-detector distance can be increased sufficiently to provide a significant improvement in the instrument's resolution, without any significant increase in weight, power, or complexity.

A major portion of the effort during the present contract was spent in the design, fabrication, testing and evaluation of a TOF system that would meet weight, power, size and other "guidelines" for lunar experiments. The performance tests made indicate that the present instrument is capable of performing lunar atmospheric analysis of all constituents of mass 1-100 possessing partial pressure above about 10^{-13} torr in a scan of only a few minutes duration, at a resolution of 100 or more. As it was intended that this program be continued, this "final" report is actually a progress report on this prototype TOF spectrometer, which, in our view, is now suitable for hardening into a lunar-environment-qualified model adequate for its proposed mission; nevertheless, many avenues of potential improvement opened in this study remain to be followed up in the future.

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INTRODUCTION

The Lunar Atmosphere

Our present knowledge of the composition and density of the lunar atmosphere is largely speculative. Polarimetric observations performed by Dollfus (Ref. 1.) indicate that the total pressure close to the lunar surface cannot exceed 4.5×10^{-7} torr, while radio astronomical observations made by Elsmore (Ref. 2.) fixed the upper limit at 1.5×10^{-10} torr at the lunar surface. Dollfus was in fact unable to detect any lunar atmosphere, but the sensitivity of his apparatus was such that if the lunar atmospheric pressure exceeded 4.5×10^{-7} torr it would have been detected. Elsmore on the other hand was able to measure the lunar atmosphere's electron density and by assuming a value for the ratio of neutral particles present to the number of electrons he derived 1.5×10^{-10} torr for the total atmospheric pressure at the lunar surface. However, F. Johnson (Ref. 3.) believes this should be corrected to a possible pressure of 3×10^{-9} torr because of Ness's (Ref. 4.) Explorer 35 studies which indicate that there is no magnetic field in the vicinity of the moon to prevent the solar wind from striking the moon.

As the lunar atmosphere is extremely thin, it has not been possible to make measurements of its composition from earth or earth orbit, nor has this been done as yet by a lunar probe. A few observatory telescopic observations of apparent gas evolution from lunar craters have been reported, with C_2, C_3, and H_2 (Kozyrev, Ref. 5. and 6.) detected spectroscopically by telescope.

Selenologists have postulated the presence of atmospheric constituents produced by a variety of processes, including volcanism, release of gas from rocks and magma, impact volatilization of lunar surface material and impacting meteorites, and accretion of solar wind constituents, as well as residua from an original atmosphere. Representative (but not exhaustive) examples of the possible constituents and the type of information knowledge of their concentrations and concentration-variations can provide are given below.

Until recently it was thought that the dominant mechanism whereby gases might have escaped from the moon's gravity was heating by solar radiation. Calculations indicated that, if the maximum temperature reached was about $400^{\circ}K$, all species up to approximately Mass 50 would have been lost over a lunar history of the order of 5×10^9 years, while those of higher mass (e.g. Xe, Kr) would largely have been retained. However, in view of recent data indicating that the solar wind may even strike the surface of the moon without deflection, thermal escape may be a considerably less important loss mechanism than solar wind "pumping" for all but the lightest constituents, so that the thermal escape lifetimes given below should be thought of as upper limits which may in fact be high by many orders of magnitude for heavy species. Gold has pointed out (Ref. 7.) that the interplanetary magnetic field is sufficiently strong to eject any ion formed in the Moon's exosphere permanently from the Moon's atmosphere, so that the residence time of any gas in the lunar atmosphere is just that time required for it to become ionized, which he estimates at less

than one month (mean life) in all cases. In this case the lunar atmosphere will (in addition to de-ionized solar wind primaries and secondaries) consist only of gases very recently released by one of the other processes listed above; one will have to look below the surface for samples for the "fossil" lunar atmosphere, if any.

Estimated lifetimes (thermal and "best estimate" including all factors) of some possible lunar atmosphere constituents are as follows:

Mass	Species	Scale Height (cm)	Thermal Lifetime*	Best Estimate (sec.) Lifetime**
1	hydrogen	2×10^8	27 minutes	22 minutes
4	helium	5×10^7		3 hours
14	nitrogen (atomic)		5 months	
16	oxygen		2 years	
16	methane		2 years	
17	ammonia		5 years	
18	water (molecule)		15 years	
20	neon	1×10^7	40 years	6 months
40	argon	5×10^6	10^8 years	6 months
44	carbon dioxide (molecule)		10^9 years	
80	krypton	2.5×10^6	10^{24} years	6 months
138	xenon	1.5×10^6	10^{41} years	1 year

* at 400°K   ** by NASA Lunar Atmosphere Working Group, Santa Cruz, August 1967

For as long as it was thought that thermal escape was the most important mechanism whereby atmospheric constituents could be removed from the Moon, the absence of a present atmosphere of the high-mass species listed above, having thermal escape times of the order of 10^9 years or more, was taken to be strong evidence either that the Moon had had no dense original atmosphere, or that it had been at a temperature markedly higher than at present long enough to evaporate-away its original atmosphere. But if the solar wind indeed strikes the moon, these arguments are invalid. While the final test of these theories must await an actual analysis of the lunar atmosphere, it is thus the present expectation that that atmosphere will be a sample of recently released gases, and particulary of solar wind residuals, and not of particles that have been in that atmosphere over a geologically long time.

The most interesting constituents for study therefore include the following:

Water Vapor — Determination of the water vapor concentration will give information on the availability of free water on the moon — a subject of great interest in planning for its future exploration. If appreciable water vapor is found, it will indicate either that there is unbound water in the surface layers of the lunar material (as postulated by Kopal (Ref. 8.) and Watson et al (Ref. 9.) or that water being brought to the surface by volcanism, diffusion, or some other process. If water vapor is pr4sent, the study of variations in its partial pressure from place to place

will be a means of prospecting for water. Hinton and Taeusch (Ref. 10.) have estimated that the average water vapor molecular density near the lunar surface is $10^3/cm^3$.

Determination of water by an Astronaut is complicated by the fact that water will be released continuously (or nearly so) from the Astronaut's own pressure suit — at a rate of approximately 0.3 gm/sec. from a vent, and also to a lesser degree, from suit leakage. This problem would of course be avoided by use of an unmanned measurement instrument, perhaps set in place by an Astronaut.

Hydrogen — Even the thermal escape time of hydrogen is very short (27 min.). The amount present will give information on solar wind intensity (the solar wind consists primarily of protons) lunar leakage rate, and the possible presence of some other constituents such as water or hydrocarbons. A spectrum identified as that of molecular hydrogen has been obtained by Kozyrev in Aristarchus crater by telescopic spectroscopy (Ref. 6.), and the incoming solar wind proton flux in the vicinity of the moon is believed to be approximately 3×10^8 protons/cm^2/sec.

Helium — There is perhaps a tenth as much helium as hydrogen in the incoming solar wind, and as helium does not combine chemically, and has the highest ionization potential of any gas, and is heavier, it will probably be enhanced relative to hydrogen in the lunar atmosphere. Helium is also produced in uranium and thorium containing rocks by the decay of the radioactive isotopes of these elements to lead — providing 6 to 8 alphas (He nuclei) for each decay.

Argon-40 — This nuclide is the daughter of the decay of ^{40}K. The amount present could potentially give information on the concentration of potassium in lunar rocks, leakage rates, the age of the moon, etc.

Noble gases — It was hoped that the relative abundances of He, Ne, Ar, Kr and Xe in the lunar atmosphere could be used, as Brown (Ref. 11.) used the same data for Earth, to make deductions on the manner of origin of the moon, i.e., the presence or absence of an original atmosphere, and extent of its loss, since Kr and Xe are very difficult to remove from the moon's atmosphere by thermal evaporation due to their high atomic weights, while the other noble gases are removed more and more easily by the thermal process, the lighter the mass. However, if solar wind pumping is indeed as effective as is indicated by the "best estimate" lifetimes given above, these species also will have been removed and any amounts present will also be newly produced. Possible sources for Xe and Kr are (1) spontaneous fission of U^{238}, (2) fission of U^{235} by thermal neutrons from cosmic rays, (3) thermal fission of U^{235} from the reaction O^{18} (α, n) Ne^{21}, and (4) β-decay of I^{129} to Xe^{129} and (5) escape of "primeval" gases trapped in rocks (Edwards & Borst, Ref. 12.). Isotopic analysis of these two gases may give information on the relative importance of these processes, as each produces a distinctive isotope pattern, and other processes such as cosmic-ray spallation can also produce the lighter noble gases. Another source is the solar wind, but this is highly selective in favor of the lighter species. Ratios of various noble gases to H in the solar wind may be more or less as follows, if the wind is a sample of the whole sun: He/H - 0.1, Ne/H - 5×10^{-4}, Ar/H - 10^{-5}, Kr/H - 10^{-9}, Xe/H 10^{-10}. But if the solar wind is instead purely exospheric in origin, it should contain even relatively smaller concentrations of the heavy noble gases.

Oxygen — Atomic oxygen is liberated in the dissociation of H_2O, CO_2, SO_2, etc. under ultraviolet irradiation and thus should be present if any of these species are present. Once formed, it will remain predominantly in the atomic form as its partial pressure is too low to make possible the rapid interaction of atoms to form molecules. Oxygen molecules, on the other hand, are likely to be dissociated in a fraction of their flight times (Spitzer, Ref. 15.). Some oxygen is probably also constantly supplied as a minor constituent of the solar wind, and the solar wind (if indeed it strikes the surface of the Moon), will contribute oxygen to the atmosphere by a second mechanism: if the lunar surface consists of rocks essentially composed of various metal oxides, like terrestrial rocks (which now must be considered very likely), then far more than half of the atoms struck by solar-wind protons will be oxygen atoms, wherever unaltered rock is exposed. Even if only 2% of the surface of the moon is unaltered, some 10^{24} oxygen atoms will be struck each second by solar-wind protons at an average flux of density 10^9 cm^{-2} sec^{-1}. The kinetic energy of the incoming protons exceeds by orders of magnitude the dissociation energies of the metal-oxygen bonds in the rocks. It therefore seems very likely that some of the oxygen atoms torn from the mineral lattices will escape the rock and enter the atmosphere. Such reduction of metal oxide surfaces has been observed in simulated solarwind experiments (Wehner et al., Ref. 16.).

Nitrogen — Nitrogen also would be largely dissociated and will only be found if continuously produced. Dissociation of ammonia and nitrates possibly present in lunar rocks may also produce some atomic nitrogen.

CO_2 – Carbon dioxide is also subject to photodissociation, though to a lesser extent than oxygen and nitrogen. Its detection would be a clue to outgassing of the interior, and/or the presence of volcanism.

CH_4, other light hydrocarbons and NH_3 — Any light hydrocarbons such as CH_4 and other volatile compounds such as ammonia would also be dissociated. Their detection as molecules in an uncontaminated atmosphere would tend to indicate relatively high current production rates.

Heavy hydrocarbons — There are some (perhaps not widely accepted) theories (Sagan, Ref. 17; Gilvarry, Ref. 18; Wilson, Ref. 19.), which postulate the presence of high-mass hydrocarbons on the lunar surface. Sagan theorizes that as much as 10 g cm^{-2} of this material was formed during the lifetime of a primitive atmosphere and that it is now buried under many meters of meteoritic debris. Gilvarry considers it possible that life may have even developed in a primitive hydrosphere, which he calculated may have existed for as long as 10^9 years; he interprets the dark rings around several maria as organic residues left behind after evaporation of the oceans. Wilson suggested that the floors of the maria might be composed of petroleum coke of inorganic origin; however, the Surveyor alpha-probe analyses were of basalt-like material. Since their evaporation rates cannot be high, any detection of heavy hydrocarbon molecules or their dissociation products in the uncontaminated lunar atmosphere would indicate their indigenous synthesis in the past, thus lending support to theories such as the above.

$\underline{C_2}$ — Kozyrev obtained a partial optical spectrum of flashes of light in a crater and in this identified bands of C_2 and possibly C_3. This can be taken as proof of present-day volcanic activity or crater outgassing, or alternatively of the formation of acetylene by the action of rising water on carbides deposited on the surface of the moon (Kozyrev, Refs. 5. and 6., Urey, Ref. 20, Cohen, Ref. 21). And on-site search for these molecules in the atmosphere should be made to obtain additional information on their origin.

Solar wind: The solar wind appears to play a triple role on the Moon, (a) transporting new material there from the Sun, (b) liberating gas from the lunar surface by sputtering, and (c) removing already present particles by collision-ejection (solar wind pumping"). The determination of the nuclidic composition of the solar wind is a first-priority experiment for obtaining information on the internal structure of the sun. If the solar wind consists entirely of protons and certain other light species, then it is a solar exospheric phenomenon of limited interest. But if it contains heavy nuclides in approximately "cosmic" concentrations, this will be proof that it is a hydrodynamic flow phenomenon and the relative abundances observed would be presumed to be those of the Sun's surface. The moon provides a suitable platform for this measurement. (Gold, Ref. 7.).

Gases introduced to the Moon by Man — We first proposed the measurement of the composition of the lunar atmosphere long before the U.S. and U.S.S.R. had succeeded in hitting the moon with rocket probes, or landing experiment-carrying apparatus there. All such materials placed on the moon by Man of course contain gaseous components which escape into the atmosphere at varying rates. Of these, the constituents and products of rocket fuels have been most important quantitatively. To the extent these constituents have not disappeared by escape from the moon or by being trapped by the moon (by chemical combination, adsorption, or cryogenic trapping), when the atmosphere characterization experiment is performed, they will be detected. Such "technical" constituents will produce a contamination spectrum that will interfere with the study of the natural constituents to varying degrees — certainly this will be true for H, C, and O as a minimum. However, the effect may not be as serious as one might at first suppose for three reasons: (a) the technical constituents will decay away with time while the natural constituents, if in equilibrium, will not, and (b) it may be possible to distinguish between the two constituents on the basis of isotope ratios (one could possibly even isotopically label the terrestrial substances) and (c) for most species the total amount of lunar gas is (expected to be) very much greater than the amount of "imported" contaminant.

There is also the possibility of using the rocket-exhaust or other technical gases as "tracers" to study gas escape and gas trapping mechanisms on the moon.

On the basis of the postulated lunar atmosphere constituents and surface pressure given above, it appears that the spectrometer selected to analyze the

lunar atmosphere should be able to detect constituents having partial pressures down to 10^{-13} torr, or less, at a resolution that will allow the separation of adjacent masses up to at least mass 40-60, and to give a somewhat poorer mass separation up to about mass 200.

Choosing a mass spectrometer for lunar atmosphere analysis

The original goal of our program was to recommend a mass spectrometer appropriate to determine the major and minor constituents of the lunar atmosphere discussed above during passage of the analyzer through the atmosphere on a collision-course to the surface. A number of different types of mass spectrometers which it appeared could be made to meet the performance requirements outlined above were considered. These included the quadrupole, monopole, pulsed TOF, coincidence TOF, and magnetic sector mass spectrometers.

The magnetic sector mass spectrometer was rejected at the outset (1965) since at the time there was a prohibition against equipment requiring magnetic fields which might adversely affect the operation of other experiments (e.g. a magnetometer) proposed for the mission. This objection may now be largely of historical interest. The quadrupole was rejected in favor of the monopole because the monopole is simpler physically and electrically — i.e., the monopole has only two analyzer electrodes while the quadrupole has four, the power supply to generate the monopole field is simpler that that used to generate a quadrupole field, and under identical operating conditions the monopole has the same resolving power as the quadrupole at half the frequency required by a quadrupole. An ordinary TOF MS can rather easily be made to operate in the coincidence mode, an additional advantage of the TOF.

Therefore, at the direction of NASA, both a monopole and a pulsed TOF spectrometer of suitable specifications were constructed, in order to compare them with the aim of determining which would be most appropriate for the then proposed Ranger-type experiment. These were breadboard, laboratory-construction instruments. The experiments performed with them, and the conclusions drawn from these are given in earlier reports (see Refs. 30 and 31).

During the period this work has been in progress, external factors have increased the relative probability that the first opportunity to perform such an experiment would be as a part of the Apollo manned-lander program. The performance of the lunar atmosphere analysis from the lunar surface has therefore received primary consideration in the present contractual period.

Development activity during present contractual period:

The statement of work in this project called for a choice to be made between a monopole or time-of-flight mass spectrometer based on their relative performance observed in laboratory models previously constructed and the requirements of the lunar mission. The time-of-flight was selected for this application because:

(1) the larger cross sectional area of the path available to the ion beam results in a much less stringent requirement of accuracy of the alignment of source and detector,

(2) the fact there need be no mechanical connection between source and detector such as the rods of the monopole allows one to use an increased separation on the Moon, and thereby improve resolution (besides, moderate resolution is adequate for this application),

(3) the simplicity of the TOF control electronics results in circuitry which would be less affected by the ambient temperature extremes of the lunar surface, and

(4) it is possible to achieve a lighter overall package, since both the circuitry and the analyzer are less complex

At the beginning of the present contractual period the apparatus on hand consisted of two breadboard spectrometers, a TOF and a monopole, each housed in an all-metal special ultra-high-vacuum system. Furthermore each analyzer had the necessary electronic control/data acquisition system with facilities for optimizing performance.

Although achieving particular specifications was not required by the contract, the goals at which the program was aimed were as follows:

1. Partial pressure measurement capability — 10^{-13} torr at a total pressure of 10^{-10} torr.

2. Total power required — less than 7 watts.

3. Total volume occupied — to be less than 0.2 cu. ft. (approx. 5" x 5" x 14").

4. Output data rate chosen to require a maximum channel band width of 2 Khz.

5. Electronics to meet specifications over an ambient temperature range from $-65^{\circ}C$ to $+85^{\circ}C$.

6. Mechanical construction — inherent capability to withstand required g-forces during acceleration and deceleration.

7. Materials — selected to minimize outgassing on the lunar surface, and meet other contract requirements.

Each of these goals has now been reached. However, in the present system pressure that can be measured has thus far been limited to above 2×10^{-13} torr by the presence of a background spectrum which, however, exhibits a dependence on total pressure. It seems highly probable that if one could achieve a total pressure of less than 3×10^{-10} torr in this vacuum chamber, the background would be less and hence the detection limit would be lower. It appears therefore that the performance of the instruments is now adequate for the proposed lunar service. The TOF has a dynamic range of over $1000:1$ for adjacent-mass species of medium mass, and is thus more than adequate for performing an analysis of the important constituents of the lunar atmosphere in this respect also.

The molecules or atoms entering the instrument may have an initial velocity along the flight tube axis equivalent to up to 3 volts without seriously degrading resolution. At the same time, molecules moving perpendicular to the flight-tube axis when ionized will reach the detector-grid if their velocities are less than about $2.9 \quad 1/_{mn}$ Km/sec (mm lusec) when the flight path is 8 inches (lab model) or $8.75 \quad 1/_{mn}$ Km/sec when it is 60 inches (proposed on-Moon spacing), where Mn is the mass of the particle under consideration.

THE TIME-OF-FLIGHT LUNAR ATMOSPHERE ANALYZER

Principle of operation of TOF mass spectrometers

In a time-of-flight (TOF) mass spectrometer one identifies a particular species by measuring the time it takes for that species to go from the ion source to the ion detector. If all ions are given equal kinetic energy $(1/2mv^2)$, then the flight time is mass-dependent, and there is a separation of ions during their passage through the flight tube, with the lighter ions, which travel faster, arriving at the detector ahead of the heavier ions.

A schematic diagram of the type of instrument developed in this work is shown in Fig. 1.

The ion source is of the two-field type, similar in principle to that described by Wiley and McLaren (Ref. 22.), and Agisher and Ionov (Ref. 23.). A potential of about 150 V is applied to SV_1 and SV_2 and A pulse of about 30V is applied to SV_1 on top of this d.c. level. During the applications of the pulse two linear potential gradients exist between SV_1, SV_2, and SV_3. The gradients are adjusted so that all ions of a given mass produced at different points in the ionization region and having identical initial velocities in the same direction arrive at the entrance to the electron multiplier detector at the same time. The focusing effect of the two-field source is not perfect, however, because of the spread in initial energy of the ions and because of their random initial direction of motion. The length of the source pulse is normally about 1.7 μs, i.e. long enough to ensure that all ions produced have enough time to leave the region between SV_1 and SV_2.

If the source pressure is greater than about 10^{-9} torr, the peaks representative of the main constituents (i.e. those exerting partial pressures of greater than 10^{-10} torr) can be shown on an oscilloscope which is triggered by the source pulse. Under these conditions it is possible to obtain as many as 10^4 complete spectra/second making the TOF well suited for observing rapid changes in gas composition.

For species having partial pressures below 10^{-10} torr, the mean number of ions arriving at the collector per source pulse is less than that required for accurate peak height definition, and although partial pressures of 5×10^{-12} torr give visible peaks on an oscilloscope display, the apparent peak heights have only qualitative significance. For the detection of parts per thousand at the lunar surface, present estimates of the total pressure require that an analyzer be able to detect species with partial pressures of 10^{-12} to 10^{-13} torr. To be able to obtain quantitative data with a TOF it is therefore necessary to add data from sufficient spectra to achieve the desired accuracy.

In principle at least, the output signal from a TOF MS could be transmitted to earth for integration. But in practice, this is not practical as the data handling capabilities of the telemetry system are not great enough. Spectral integration is

accomplished in the present apparatus by "gating" the ion beam entering the detector. A gating pulse is applied to S_2 so that only during the application of this pulse can ions enter the electron multiplier. By opening the gate at a fixed time after the application of the source pulse the partial pressure of any particular gaseous constituent can be monitored, and by opening the gate at gradually increasing time intervals, a complete mass spectrum can be constructed and spectral integration thereby accomplished. The relatively slowly varying analog output of this system can be telemetered to earth with ease.

Construction Details - Prototype Lunar TOF.

The present TOF mass spectrometer is shown in Fig. 2 as it presently is set up in the laboratory (i.e. in a self-contained vacuum system). The source is shown schematically in Fig. 1. The various electrodes are made of stainless steel; a 3.0 mil tungsten filament is used as the source of electrons. A 20-stage "venetian blind" electron multiplier (Nuclide type EM-4A) with a number of entrance grids for modulation of the ion beam with the gating pulse is used as the ion detector. The source and detector are mounted on identical Ultek flanges which are bolted to the ends of a 38-1/2" long, 2 7/8" diameter stainless steel tube, providing an effective ion flight path of about 18".

The system is evacuated by a mechanical pump, zeolite absorption pump and 25 L/S triode ion pump. Gases can be introduced into the system via a fine variable leak (Granville Phillips Series 9100), and the analyzer tube, leak, and various valves can be baked at $450^{\circ}C$. Pressures in the low 10^{-8} torr range are routinely obtained without bakeout; the 10^{-10} torr region can be reached with bakeout.

The vacuum system shown in Fig. 1 is of course necessary only in the terrestrial laboratory. The total pressure at the Moon's surface is expected to be in the high vacuum region, below 10^{-8} torr rather certainly (see above). Therefore the weight of this system, the pumps, etc. can be ignored. The source and detector show assemblies per se are very light, as figures 3A and 3B. It may be possible to run the instrument "nude" on the moon, but more probably a very light-gauge tube should be used to shield the flight path from the lunar environment.

Special protection may be required for the electron multiplier, because of the presence of energetic ionizing particles, to reduce the spurious count background. Here, operation of the instrument in the "coincidence" mode (with the detector "open" only after an ionizing event in the source has triggered it, until an ion arrives) offers one way out, albeit at the cost of some sensitivity, since inherently by its manner of operation the coincidence TOF is not able to cope with ion currents as large as we expect in the non-coincidence TOF if the pressure on the Moon is indeed in the 10^{-9} torr range.
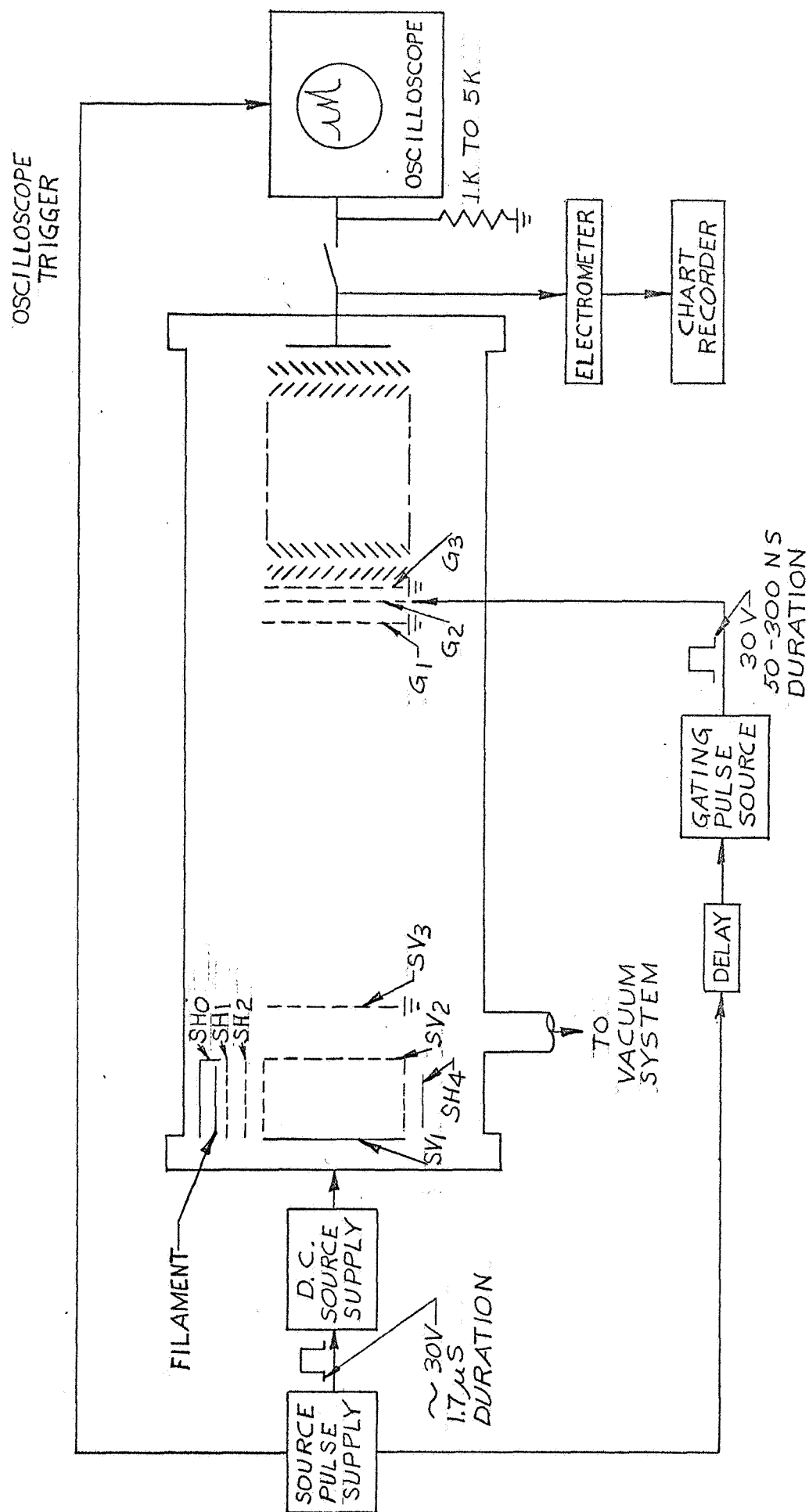
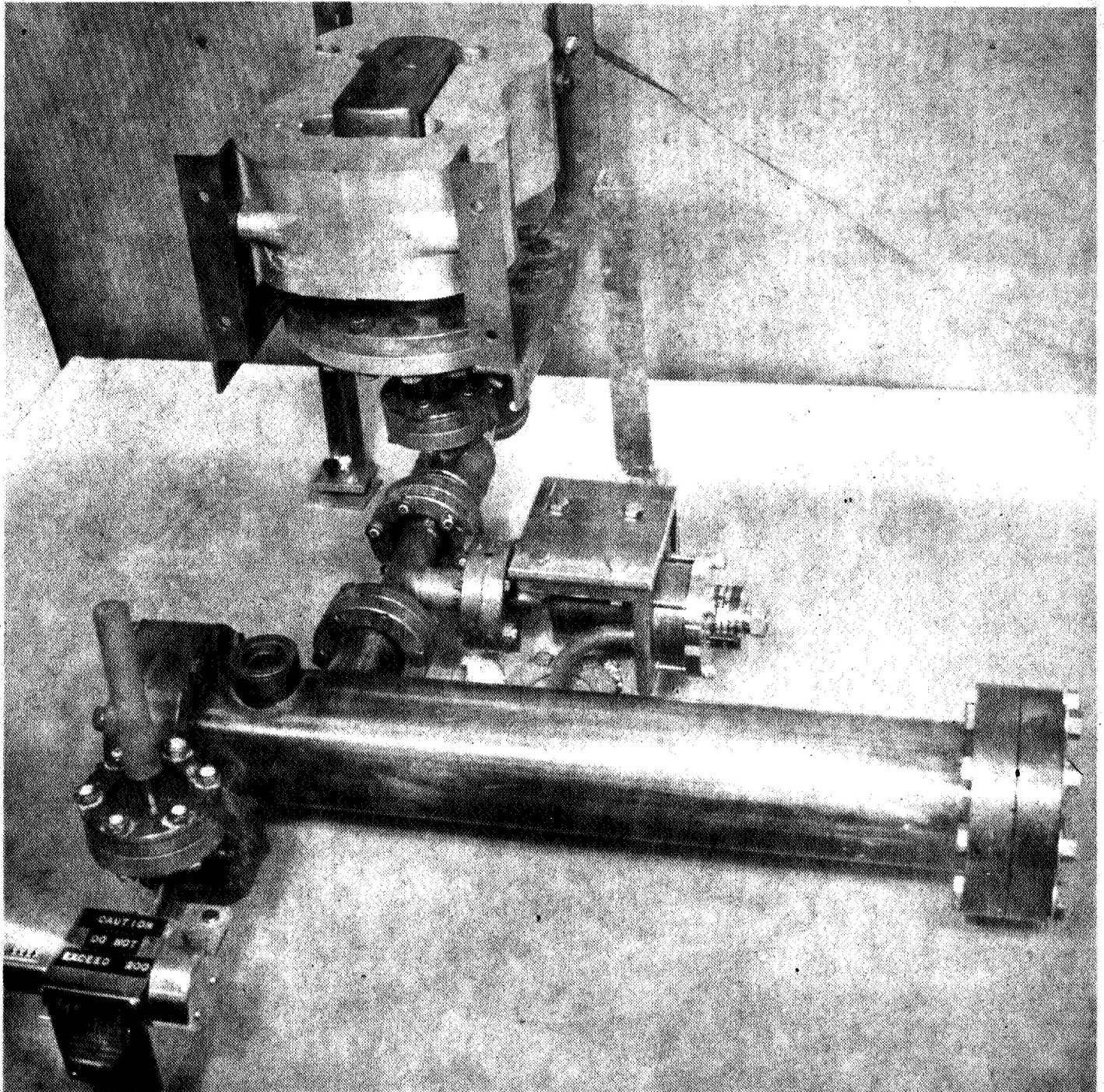FIG. 1   SCHEMATIC DIAGRAM OF LUNAR T.O.F. MASS SPECTROMETER

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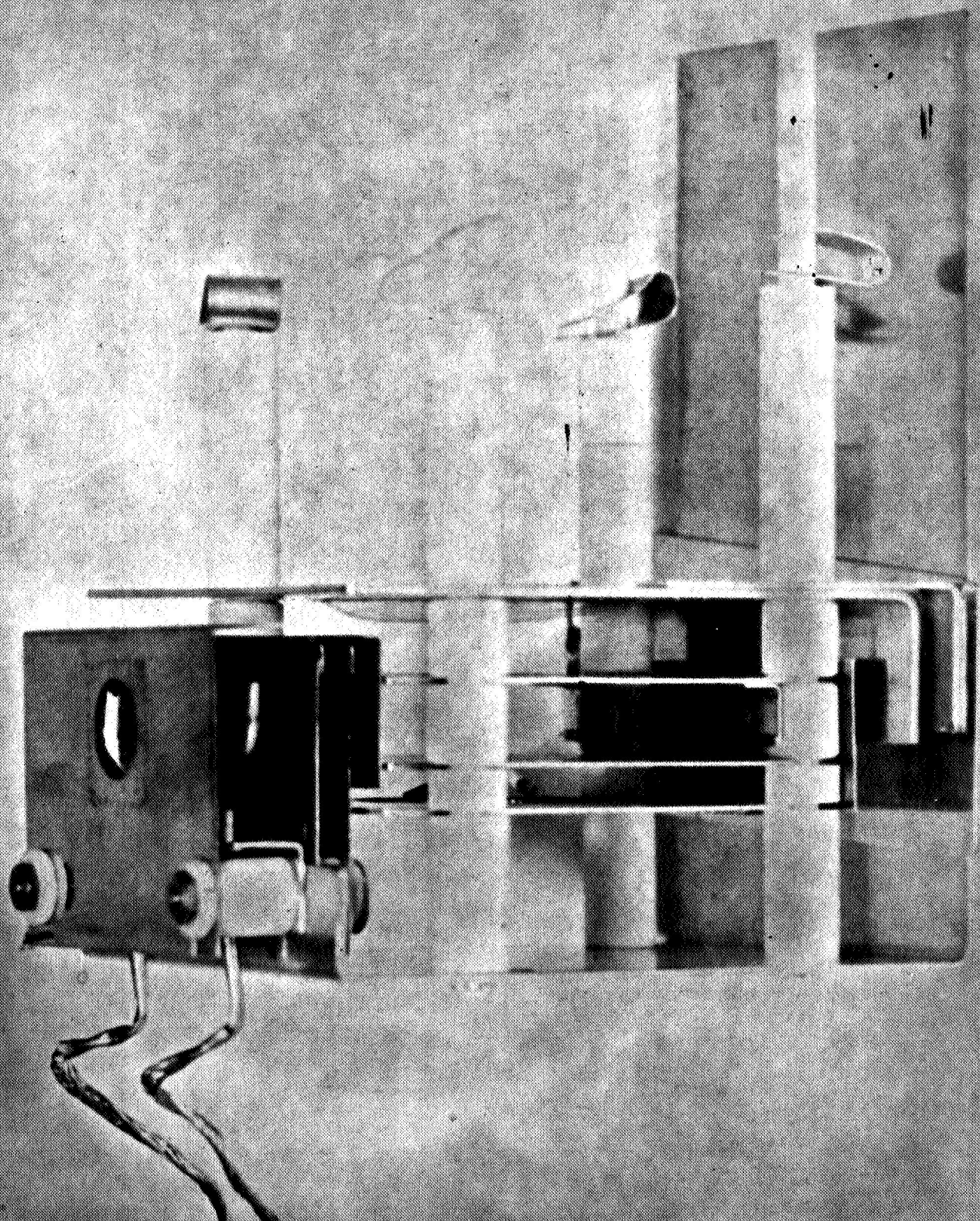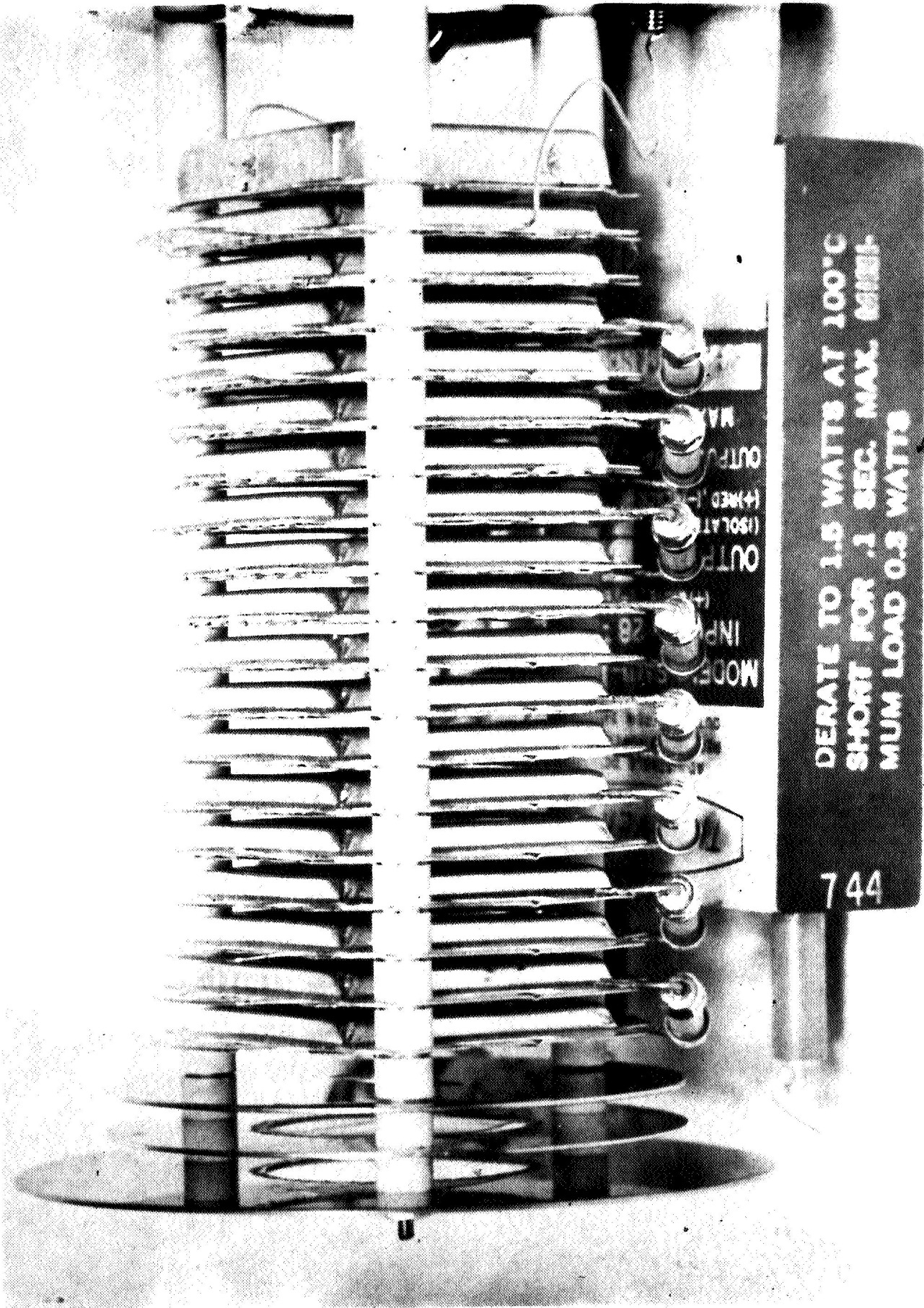
Fig. 2 TOF Mass Spectrometer

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Fig. 3A

Fig. 3B

Present TOF Electronics

A block diagram of the entire TOF electronic control system is shown in Figure 4.

Power Source: The primary power source tentatively scheduled for the Apollo Lunar Surface Experiment Package is a radioisotope thermoelectric generator (SNAP-27) with a Pu-238 fuel capsule heat source. This has a 56 watt (28V, 2 amps) capacity. As detailed specifications for SNAP-27 were not available, the electronic circuitry was designed to perform as specified for a $\pm$ 10% input voltage change. The numerous voltages needed to operate the TOF source dictated a need for a power converter. The circuit shown in Figure 5 is a dc-to-dc converter operating at 6000Hz chopping frequency. In this way the 28V is transformed to provide the various source potentials and filament power.

The level of performance realized with the unregulated power converter suggests that a further improvement in noise level would result from using either a filament or trap current regulator. Originally, provisions were made to include in this a 3KV supply (low current) to power the electron multiplier; however, as in the interim a 3KV supply that can be powered directly from 28 VDC has become commercially available, it has tentatively been decided to use it, thus obviating the need for designing this supply.

(General): The Ion Source Pulse (ISP) is in reality the clock for the entire system, in addition to establishing the gradient necessary between SV1 and SV2 (the ionization region) to cause the ions to enter the driftspace between source and collector with an energy equal to SV1 + ISP, o-p. The ISP triggers two electronic circuits simultaneously, a slow sweep and a fast ramp, the latter occurring once for each ISP, the former triggering only once every i th time, where i is the number of samples taken in presenting an integrated (averaged) spectrum. The increasing time-delay between the occurrence of the ISP and the ion gating pulse is controlled with a circuit (Sweep Compare Circuit, SCC) which compares the amplitudes of the fast ramp and slow sweep; as the slope of the slow sweep is many orders slower than that of the fast ramp, the time interval between ISP and the time at which the two voltages are identical increases with the slow sweep voltage. The SCC triggers the Gating Pulse Generator (GPG) to produce a constant-width gating pulse superimposed or a d.c. bias potential (V_{BP}), and applied to the gating grid in front of the electron multiplier. The system is, in principle, similar to that described by Wager (Ref.24.).
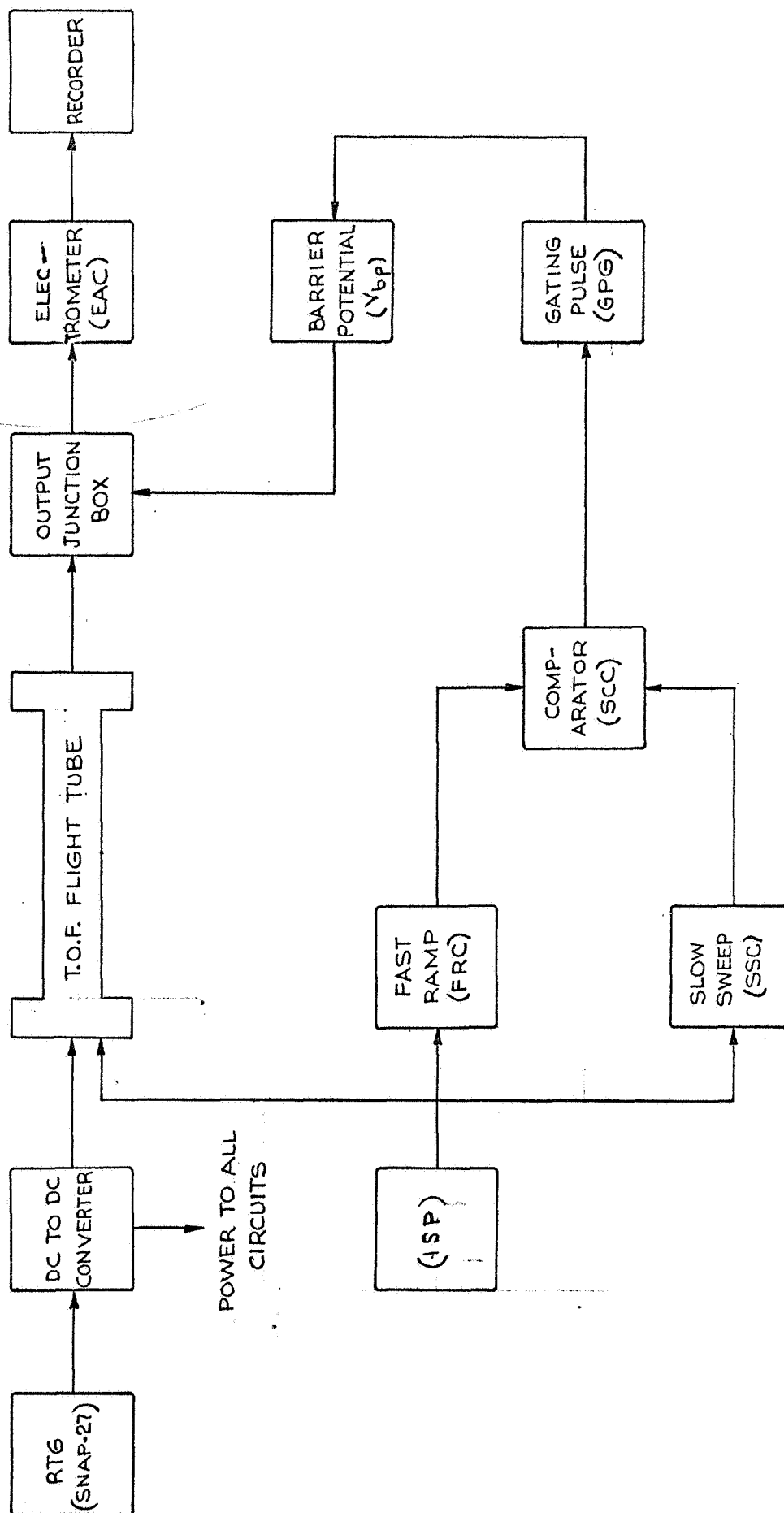
FIGURE 4 - T.O.F. ELECTRONIC CONTROL SYSTEM (BLOCK DIAGRAM)

FIG.5 DC TO DC CONVERTER

Fig. 6 shows the output waveforms from the various system component circuits and shows the relationships (in time) of one waveform to the others.

Fig. 6a.   represents the fast ramp
Fig. 6b.   represents the slow ramp
Fig. 6c.   represents the output from the comparator
Fig. 6d.   represents the gating pulse
Fig. 6e.   represents the source pulse

Fig. 7.   is a photograph of the actual waveforms.

Fig. 7a.   is the slow ramp
Fig. 7b.   is the reset pulse for the slow ramp
Fig. 7c.   is the fast ramp
Fig. 7d.   is the monostable output which controls the duration of the fast ramp
Fig. 7e.   is the comparator output
Fig. 7f.   is the ion source pulse

It was not possible to show the gating pulse on the time scale of Fig. 7 . because of its very short duration.

Varying the length of the slow ramp at a fixed source pulse frequency varies the number of samples per integrated spectrum, while varying the length of the fast ramp varies the mass range of the integrated spectrum.

The various component circuits of the gating system are discussed in some detail below.

Fast Ramp Circuit (FRC)

The fast ramp is generated using the basic Miller circuit with high speed reset controlled by Q1 (see figure 8). Q2 provides the necessary gain and inversion; Q3 and Q4 are used for isolation and supplying low output impedance. The mode control voltage requires that +28 volts will reset the output to near zero while 0 volts will allow for generation of the fast ramp. This voltage is generated by a monostable circuit (Mode Control Monostable, MCM), Figure 9, triggered at each ISP to deliver an output pulse of 80ms duration (nominal).
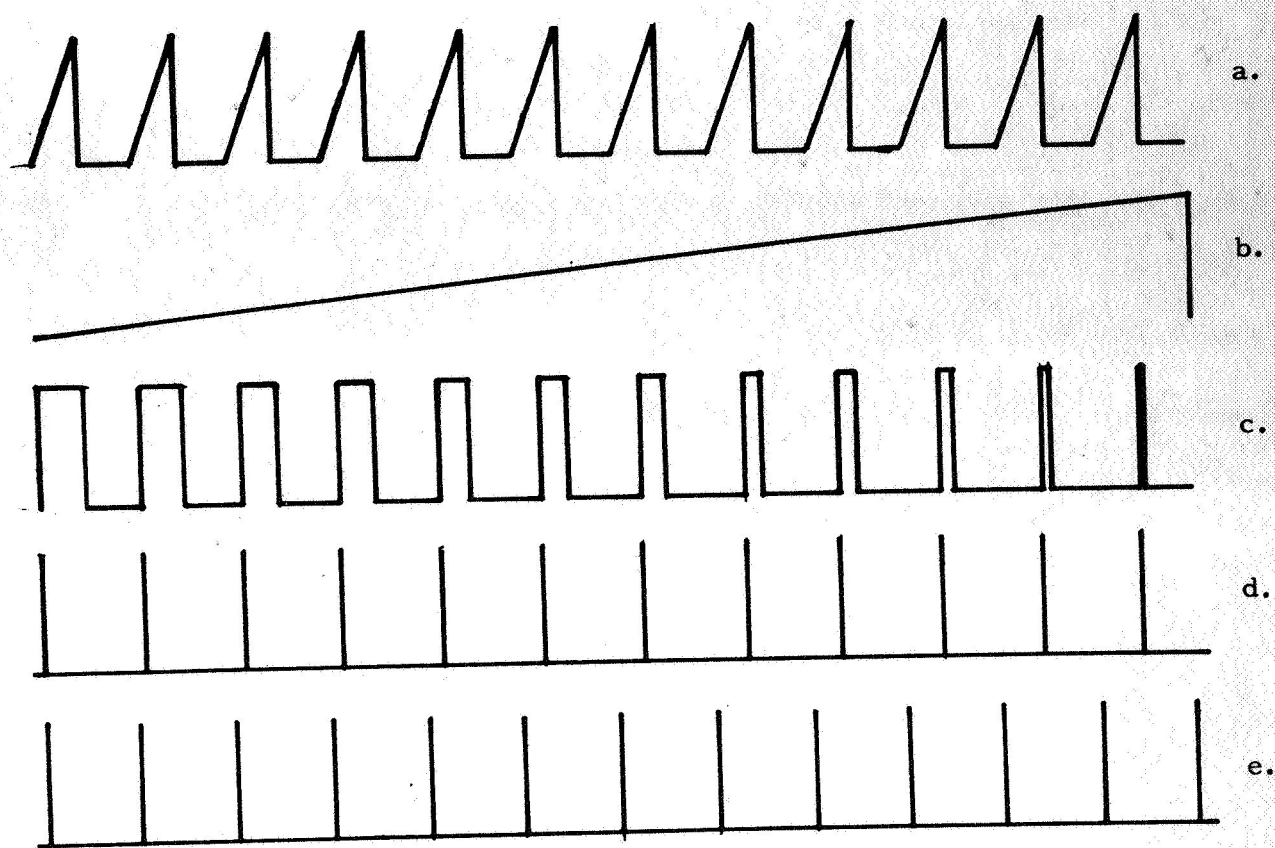
a.

b.

c.

d.

e.

FIG. 6   GATING CIRCUIT PULSES
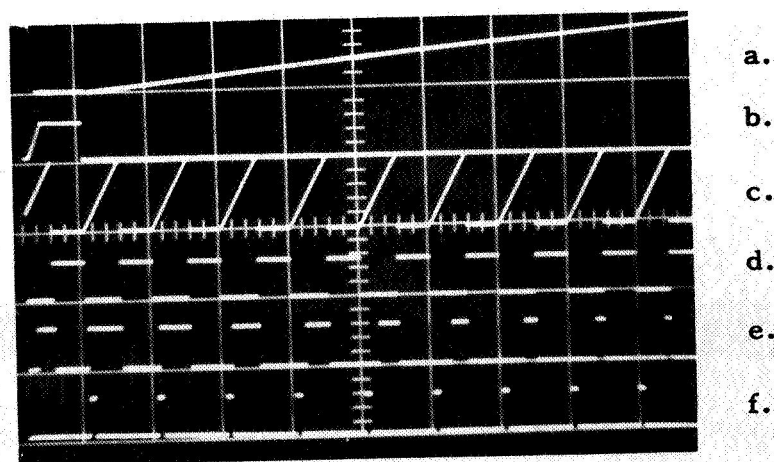
a.
b.
c.
d.
e.
f.

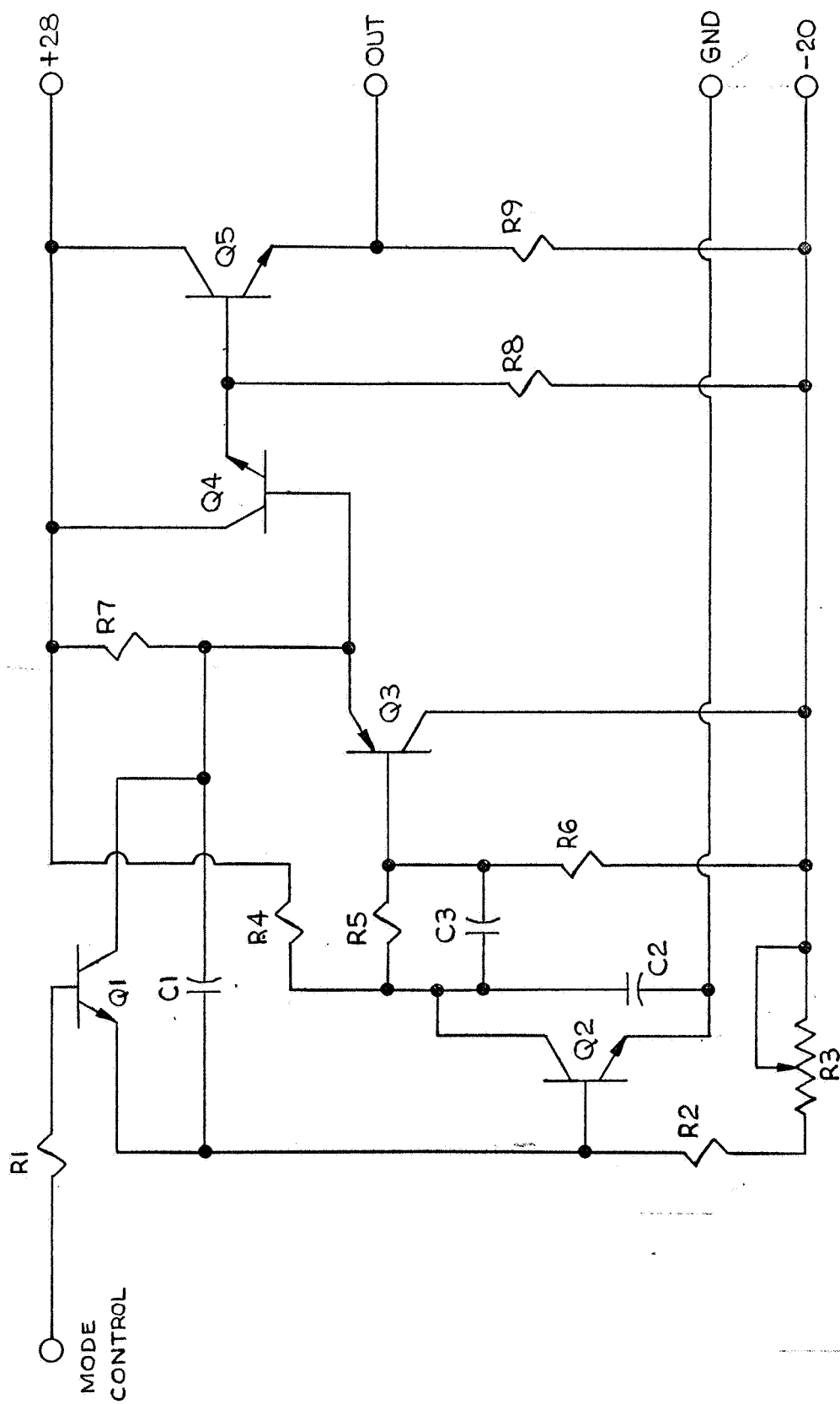FIG. 7 OSCILLOSCOPE DISPLAY OF PULSES IN GATING CIRCUIT

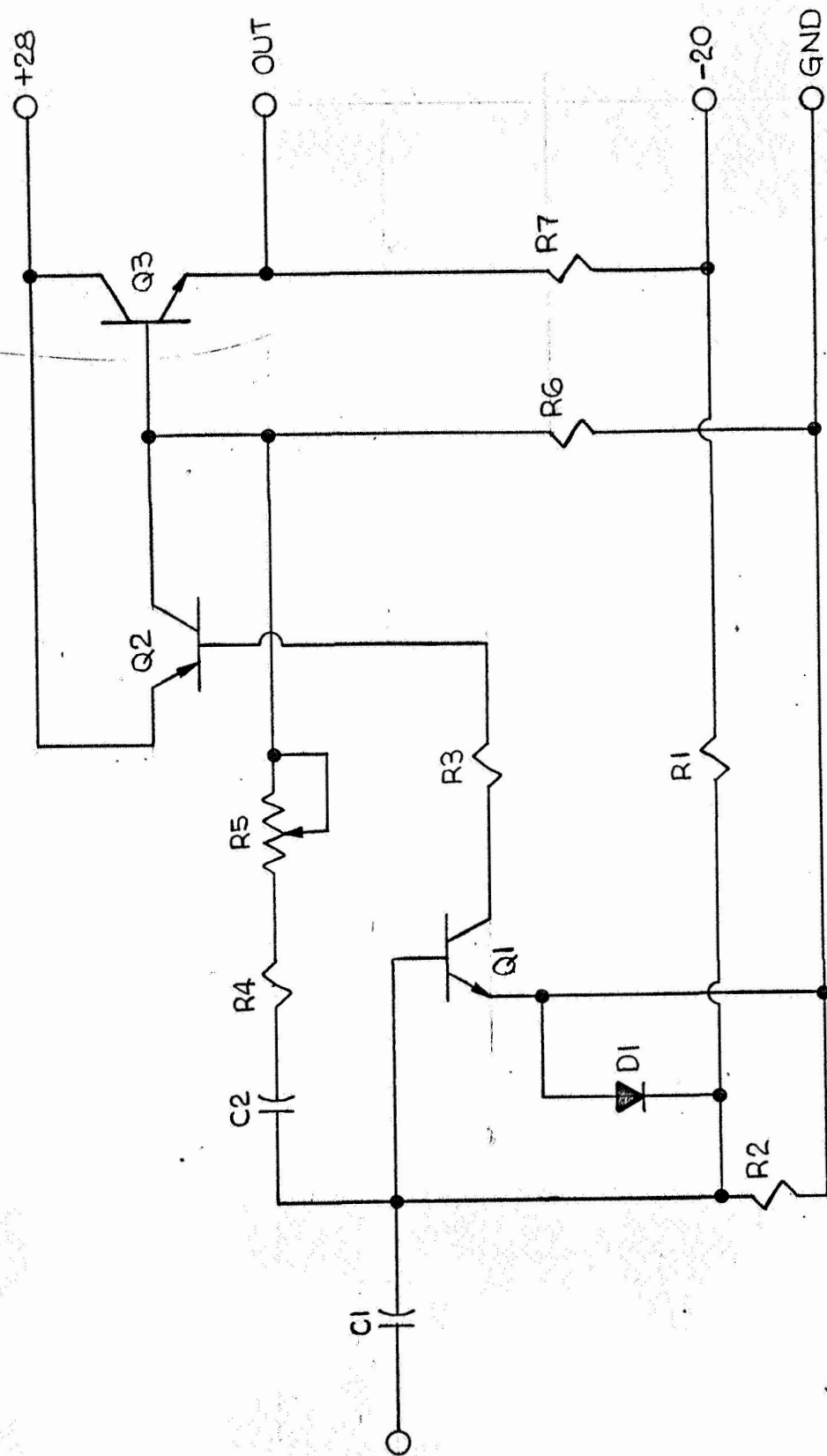FIGURE 8   FAST RAMP CIRCUIT (FRC)

- 20 -

FIG. 9   MODE CONTROL MONOSTABLE (MCM)

Slow Sweep Circuit (SSC)

The slow sweep circuit, Figure 10, employs a single stage amplifier with capacitive feedback; the input terminal is connected to a constant current source. Because of the high impedance level at this point it was necessary to use a field-effect transistor. Reset is accomplished by utilizing the voltage swing at the gate terminal, which reaches roughtly -3VDC when the output is at +20VDC. A circuit that will deliver a predetermined pulse of several minutes duration and at the same time be reset and triggered within a 100 MS time interval is difficult to design. Consequently a comparator was used to sense the output reaching the + 20 volt level and to preset the static control inputs of a third circuit, an R-S-T flip-flop, which triggered on the next ISP to again start the slow sweep. In this manner it was possible to realize a trigger rejection ratio (sweep time/ISP repetition rate) up to $10^7 : 1$.

Sweep Comparator Circuit (SCC)

The comparator requirements were demanding, in that low-hysteresis and fast-rise output were necessary to minimize the time delay from clock pulse to sampling pulse. The circuit used was an NPN-PNP complementary d.c. amplifier (similar to the pulse shaper) with the reference input connected to the emitter of Q_1. The hysteresis is a function of the R_3/R_{in} ratio, as the feedback path forms a voltage divider which couples a portion of the output voltage to the base of Q_1. Should the ratio become too small, the circuit will "latch-up" once the input is triggered. The lower limit is defined by

$$\frac{R_{in}}{R_3} = \frac{V_{be}\ (min)}{V+} = \frac{0.30\ volts}{30\ volts} = 0.01$$

where

R_{in} = the parallel combination of R_1 and h_{ie},

and R_3 = feedback resistor.

However, the closed-loop forward gain decreases in proportion to the R_{in}/R_3 ratio, so some compromise must be made between hysteresis and switching speed (switching speed 0 closed loop gain). The details of the comparator circuit can be seen in Fig. 11.
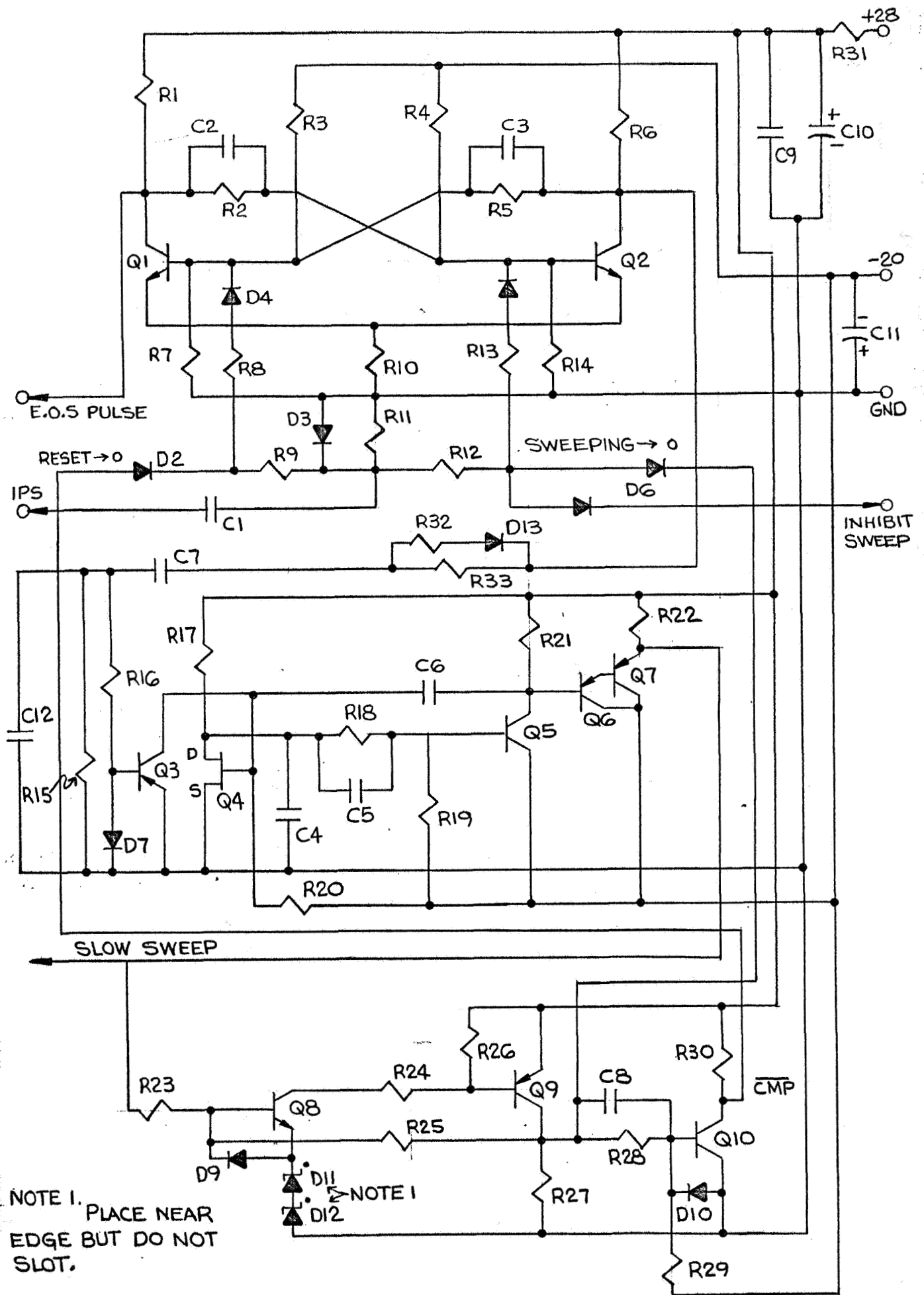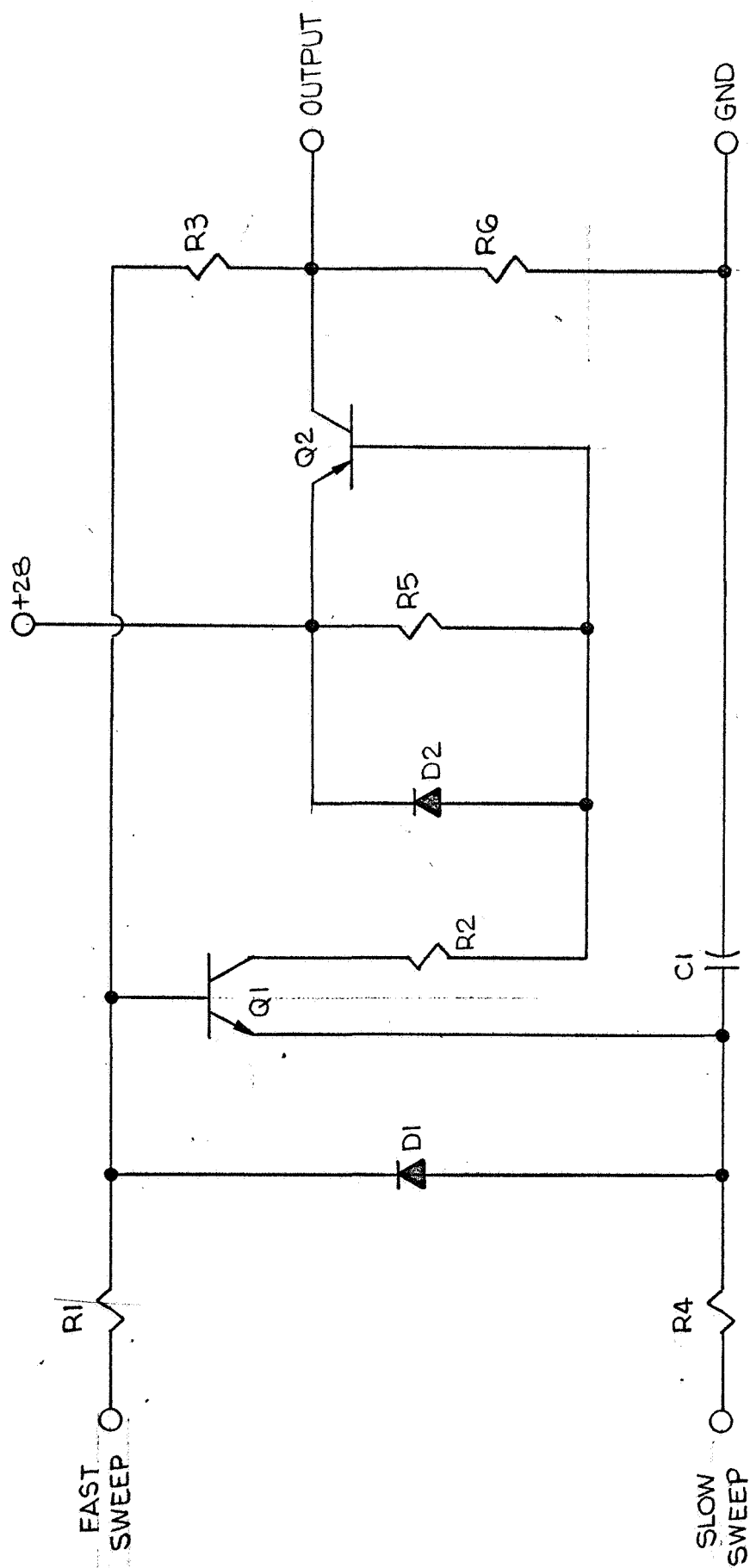
FIG. 10   SLOW SWEEP CIRCUIT (SSC)

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FIG. II SWEEP COMPARATOR CIRCUIT (SCC)

Gating Pulse Generator (GPG)

A pulse generator (Fig. 12) was needed to supply a very fast, constant-width, negative pulse on the order of 30 volts amplitude, the instant the comparator output indicates the amplitude of the fast ramp to be larger than that of the slow ramp. The pulse width, adjustable from 50 ns to 300 ns, is defined as

$$\text{pulse width (tw)} = t_r + t_{on} + t_s + t_f$$

where

$$t_r = \text{risetime}$$
$$t_{on} = \text{width of pulse measured at 90\% points}$$
$$t_s = \text{storage time}$$
$$t_f = \text{fall time}$$

Since the best rise and fall times that can be expected (with the transistors used) are 20 ns, the storage time must be minimized to allow for at least 10 ns on-time. The load presented to the generator will be primarily capacitive as the d.c. impedance of the plates in the gating device is virtually infinite, excepting leakage across the glass insulators to ground. The capacitance of the plate was calculated to be about 20 pf with the wiring and stray capacitance being at least double that figure. The estimated total capacitance was approximately 80 pf.

As the gating system is designed to allow ions to enter the detector only during the application of the gating pulse, it is necessary that this pulse be applied to the gating electrode on top of a d.c. potential that is at least as great as the ion energy. This is implemented by superimposing on the barrier potential, V_{bp}, the output pulse coupled from the low impedance emitter-follower, Q_4, through the output impedance of the variable power supply that supplies V_{bp}.

Q and Q form a high-gain, non-inverting, amplifier with an open-loop gain of 5×10^3 (typical). Even higher gain is possible when a portion of the output is fed back to the input. The output pulse width is determined by the time constant of the RC input network. The input voltage swing is typically 0-30 volts but obviously, with the gain available, only a few hundredths of a volt is needed to cause the output to reach 30 volts. Thus, by sacrificing amplitude, the input time constant can be made very small and a very narrow output pulse obtained as a consequence, i.e. 50 ns as measured at 50% points. Q_3 performs an inversion of the output at the collector of Q_2, and Q_3 provides the low output impedance for driving the capacitive load. D_3 limits any high voltage transient from V_{bp} from reverse biasing the emitter-collector junction.
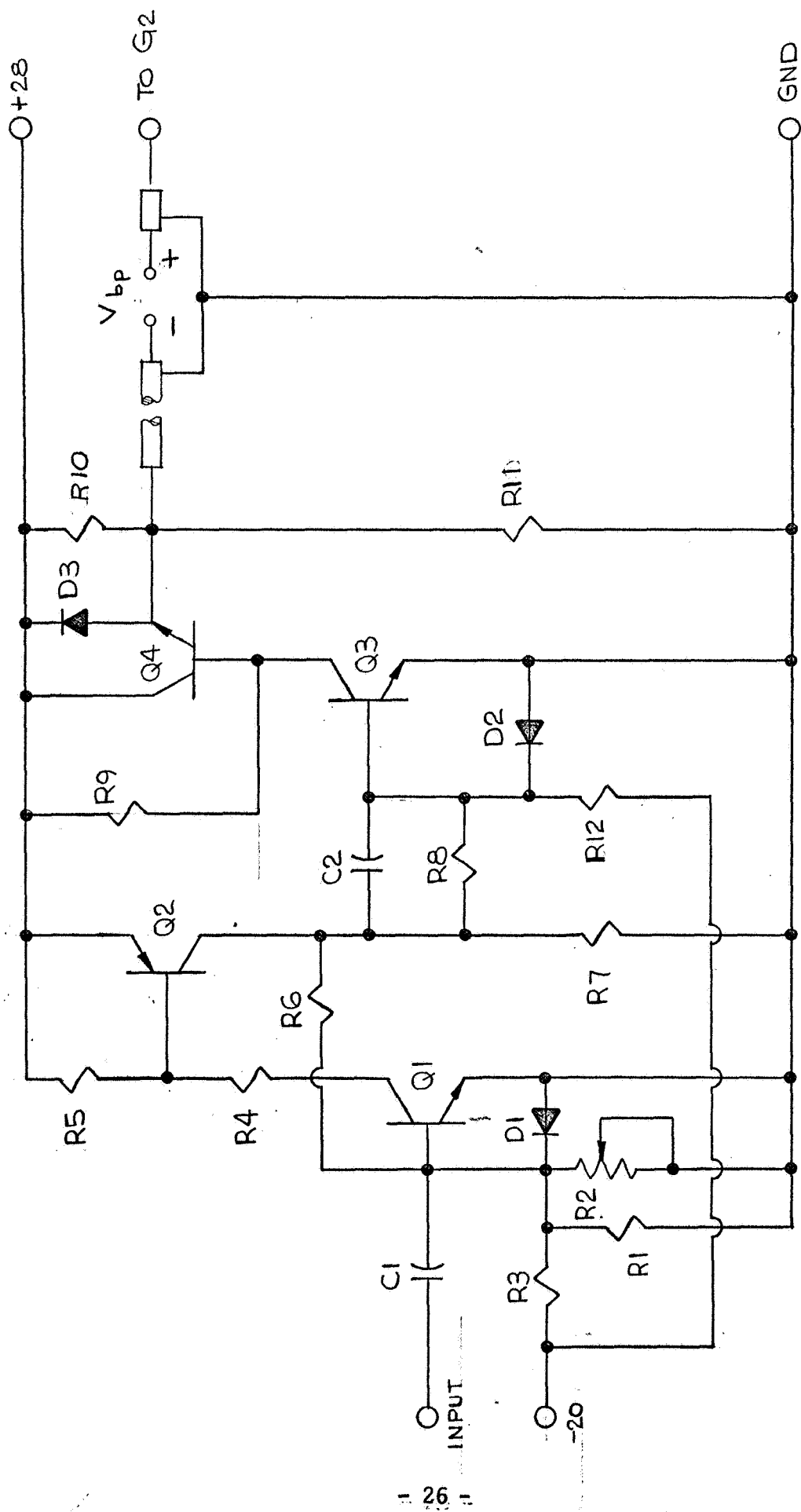
FIG. 12 GATING PULSE GENERATOR (GPG)

COLLECTOR ELECTRONICS

General

The gated detector-multiplier schematic is shown on Fig. 13. The spacing between G1, G2, and G3 was selected on the basis of required time to allow the slowest moving ions sufficient time to traverse the G1-G2 region. The input grid, G1, is grounded to maintain a field free drift space. The gated grid, G2, is biased to approximately the ion energy level (in absence of the gating pulse). Grounding of G3 firmly defines the gradient from G2-G3. The conversion dynode in the electron multiplier is held at -2500 volts; thus any ions permitted to pass through the gated detector are accelerated prior to entering the multiplier. The electron multiplier is powered by a Thin-Verter^{TM}, model SMU-3A, Arnold Magnetics, which operates directly from the RTG.

Electrometer Amplifier Circuit (EAC)

A hybrid amplifier, Fig. 14, was designed to condition the output of the electron multiplier to fall within the dynamic range of the telemetry system. Long term drift is minimized by employing a +15 volt regulator to power all critical stages. Changes in the -20 volt supply do not affect the performance of the circuit as the minimum signal level at Q3 is in excess of the expected environmental extremes. As a result of this testing program the power supply reference diode was selected to exhibit less than 500 uv drift for an ambient temperature change of $100C^O$ (25^OC to 125^OC). The effective gain by which a change in supply voltage is multiplied in effecting a change in output voltage is approximately 16. Thus for a 10^{10}ohm input resistor the resultant temperature coefficient is 8×10^{-15} amp/$_{O_C}$. The conclusion here is that the power supply as designed will not contribute significantly to the net drift of the entire amplifier when subjected to change in ambient of $100C^O$.

Electronics Fabrication

A photograph, Figure 15, shows the cordwood type assembly used in packaging the electronics. The complete electronics system is shown except for the converter which was not built since this particular circuit would need be optimized with the entire system operating in an appropriate lunar simulator.
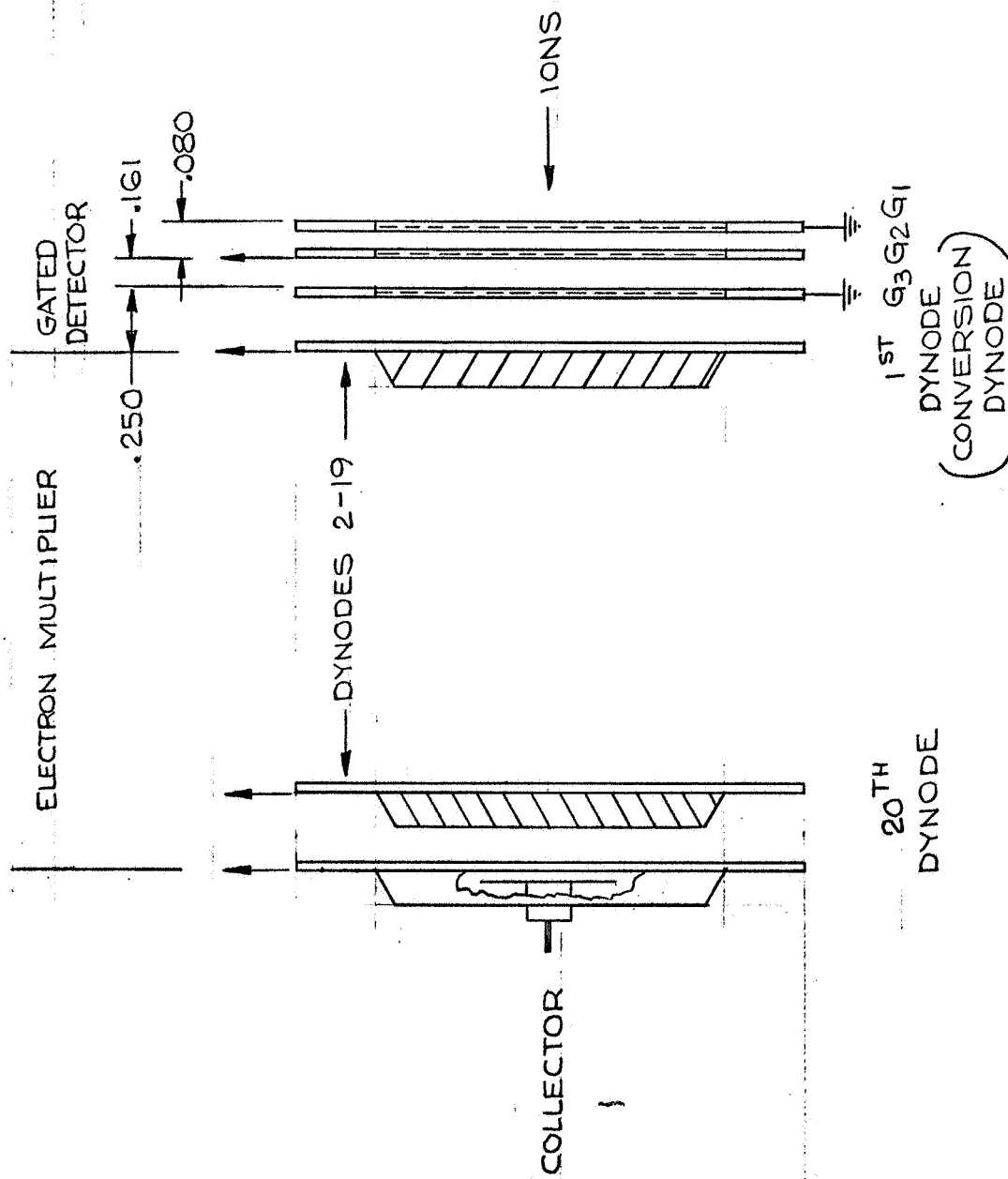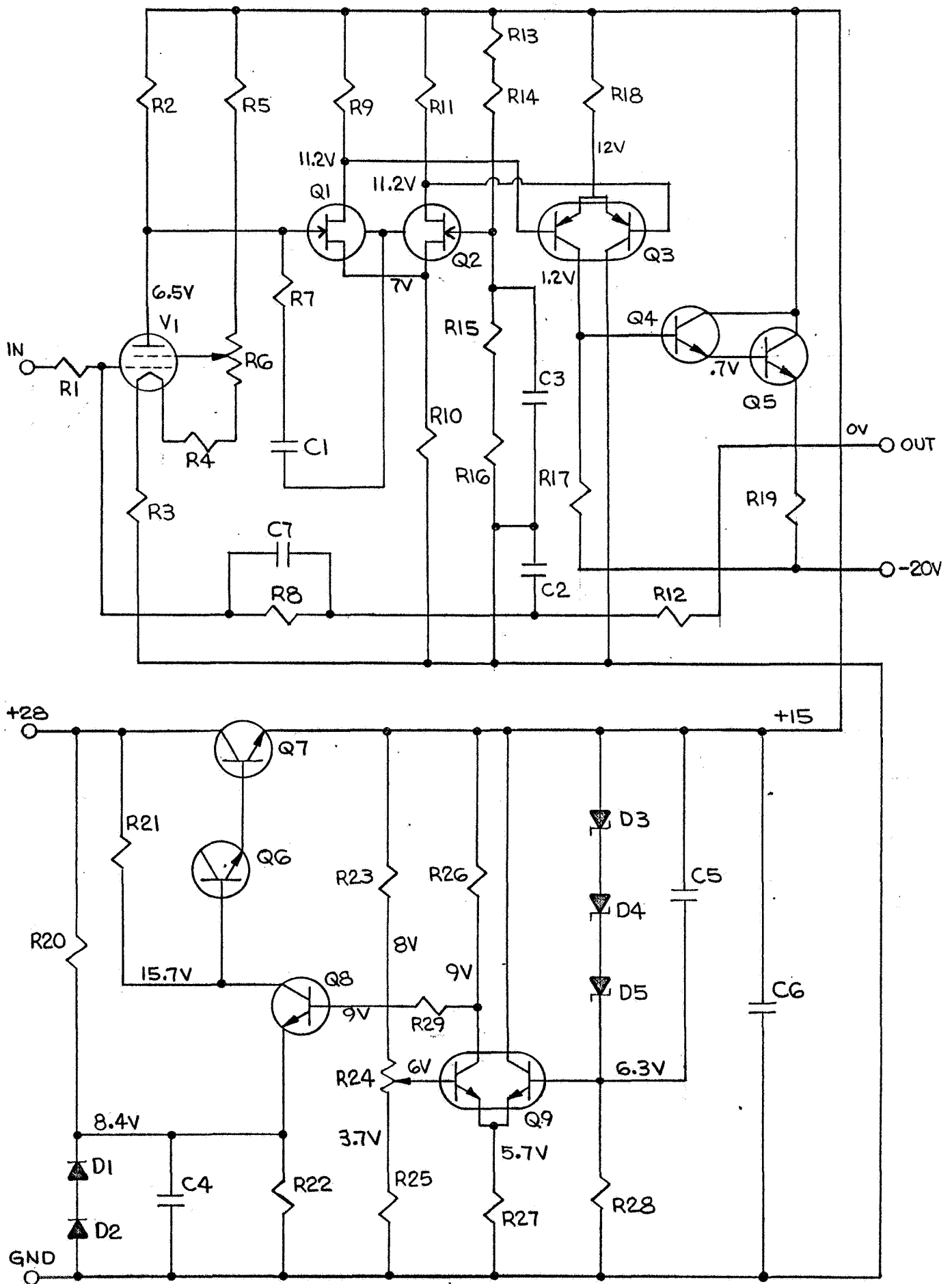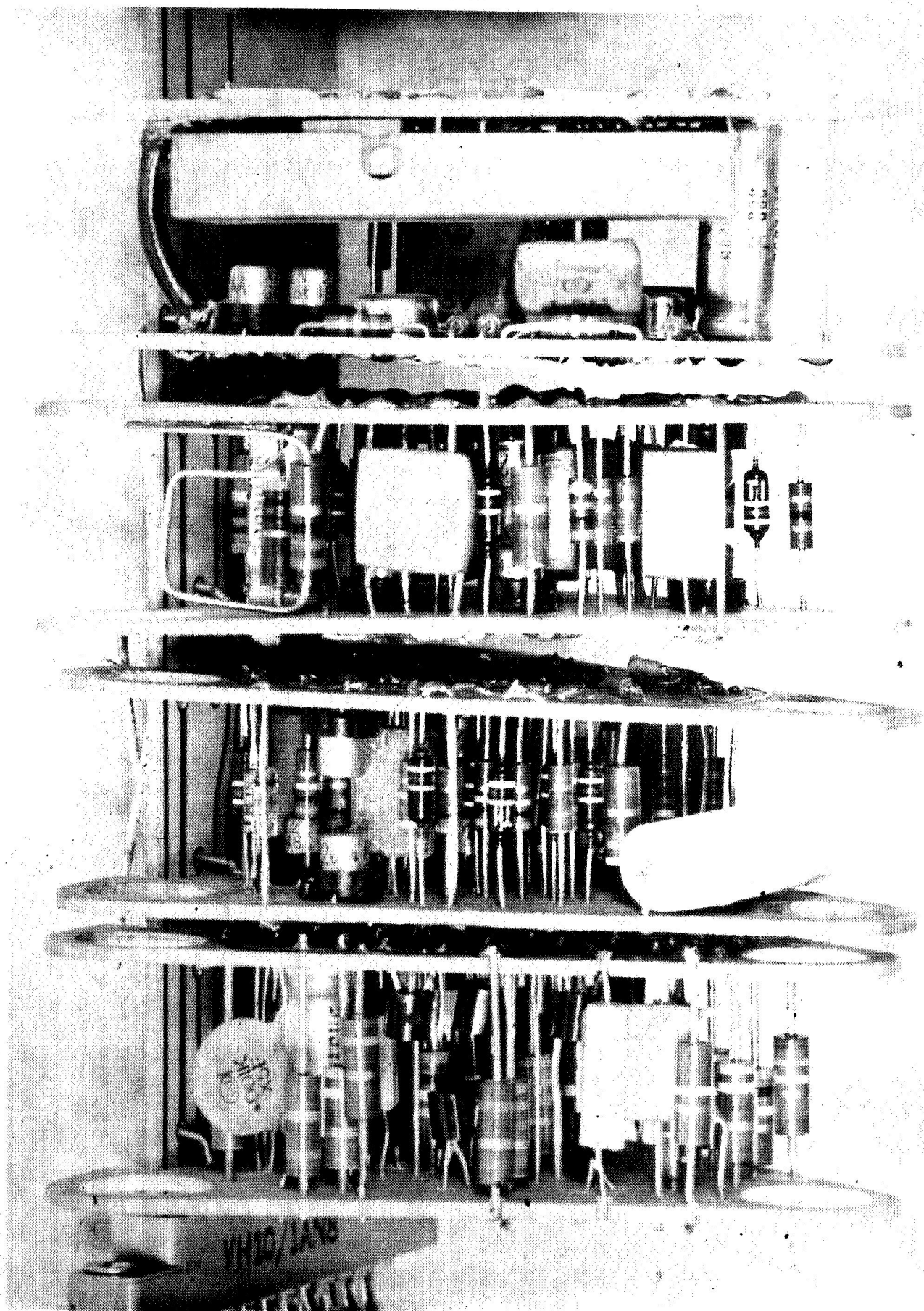
FIG. 13

FIG. 14   ELECTROMETER AMPLIFIER CIRCUIT (EAC)

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Fig. 15

PERFORMANCE TESTS

The results presented in this section illustrate the performance of the TOF under various operating conditions.

Fig. 16 shows the residual spectrum at a total pressure of 7×10^{-10} torr. The vertical scale is calibrated at 4.5×10^{-11} torr/inch; the horizontal scale at 1 minute per inch. The ISP repetition rate was 5 Khz. The total time required to record this spectrum was 7 minutes. Using this information, the number of samples taken in integrating the spectrum is computed at 2.1×10^6 for a SNI of approximately 10^3 over the S/N measured in repetive mode.

Fig. 17 is a photograph of the spectrum in the non-gated mode as monitored on the oscilloscope.

Fig. 18 shows the partial pressure measurement capability of the present TOF system. The vertical scale here is calibrated at 1.1×10^{-12} torr/inch. Measured from the average base line, the mass 13 peak at 8×10^{-13} torris easily distinguished as the noise,o-p, is approximately 3×10^{-13} torr.

A sample of Heptane, C_7H_{16}, was used for tests. Fig. 17 shows a heptane spectrum obtained in the non-gated mode, while Fig. 19 shows a comparable spectrum with the instrument operated in the gated mode. The parent peak at m/e 100 is clearly distinguishable and the lower hydrocarbon groups are clearly resolved. The horizontal (sweep) scale is 30 sec./inch. The resolution as calculated from the full peak width at 50% of the mass 18 peak height is approximately 60. With the increased flight path (60 inches or more) intended to be used in the final model, the expected improvement of resolution would easily be twice that observed, as resolution increases linearly with flight path unless limited by underdesigned electronics.

Fig. 20 shows the TOF's capability at a scan rate of 5 sec/inch (approx. 0.5 sec/amu at mass 30). In this case the pressure is 2×10^{-9} torr, a factor of 10 lower than in the other spectrum. Note that the resolution is not worse, perhaps even a bit better than in Fig. 19, however, the decrease in results in scan time results in decrease in sensitivity. (The apparent partial pressure scale is set at 10^{-10} torr/inch.) However the spectrum demonstrates that at a total scan time as small as one minute species present to the extent of 10^{-12} torr would be detected.

The optimum setting for barrier potential, V_{BP}, as related to the ion energy was determined experimentally. Two interesting effects were observed. Namely:

1. That the shape of S/N vs (V_{BP} - ion energy) curve, Fig. 21 a,b, is influenced largely by the magnitude of the ion energy. The optimum S/N setting is more clearly defined for higher ion energies (200 volts). The same curve for ion energy on the order of 150 volts is very broad in comparison to the 200 volt curve.
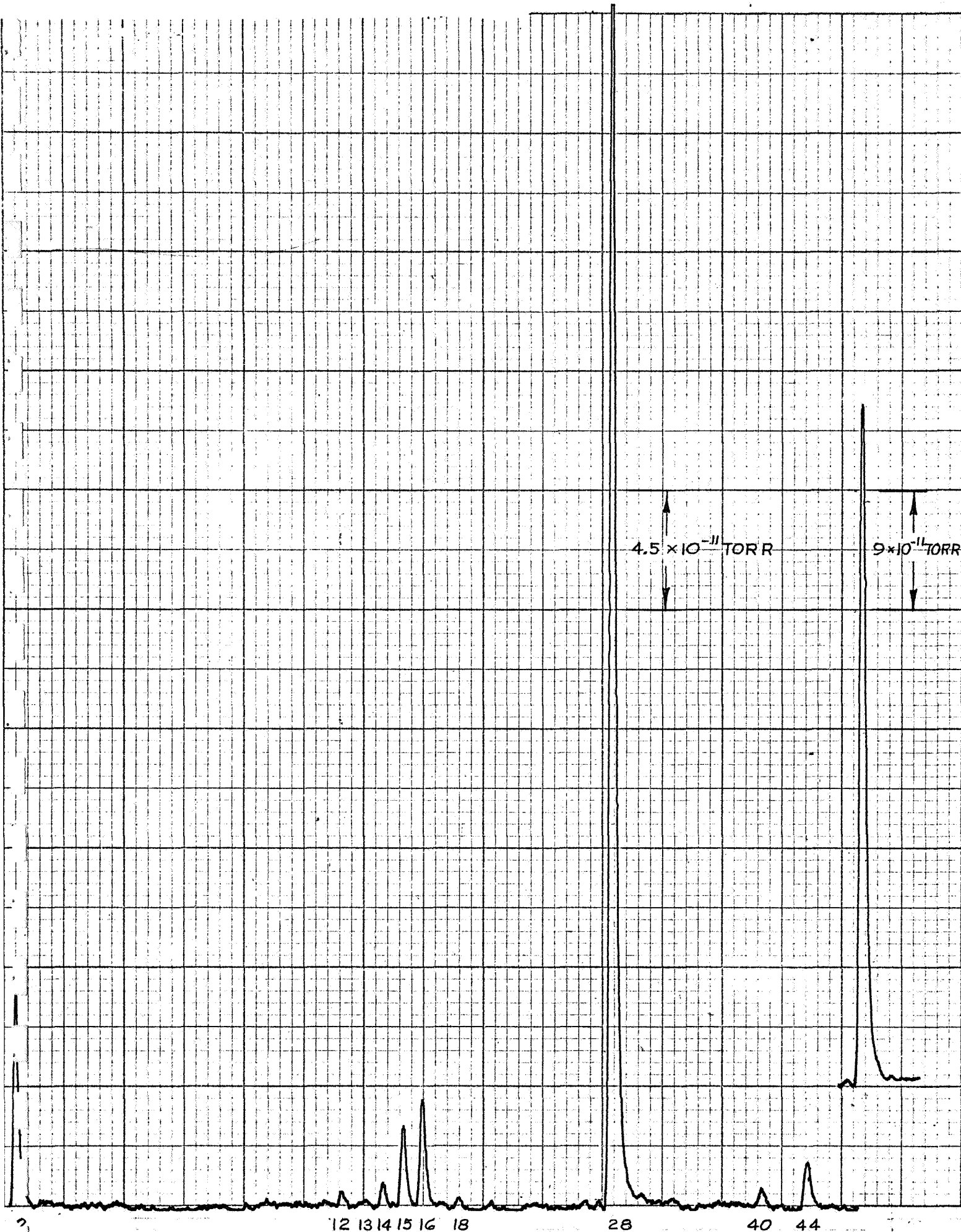
FIG. 16 T.O.F RESIDUAL GAS SPECTRUM WITH 50 NS GATING PULSE
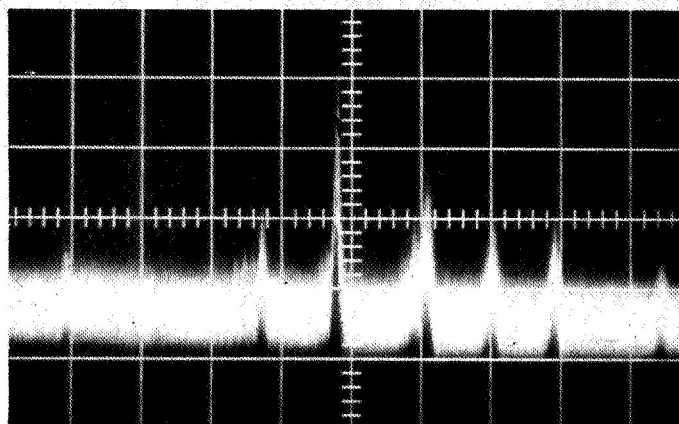
FIG 17

OSCILLOSCOPE DISPLAY OF T.O.F. SPECTRA-NON-GATED MODE
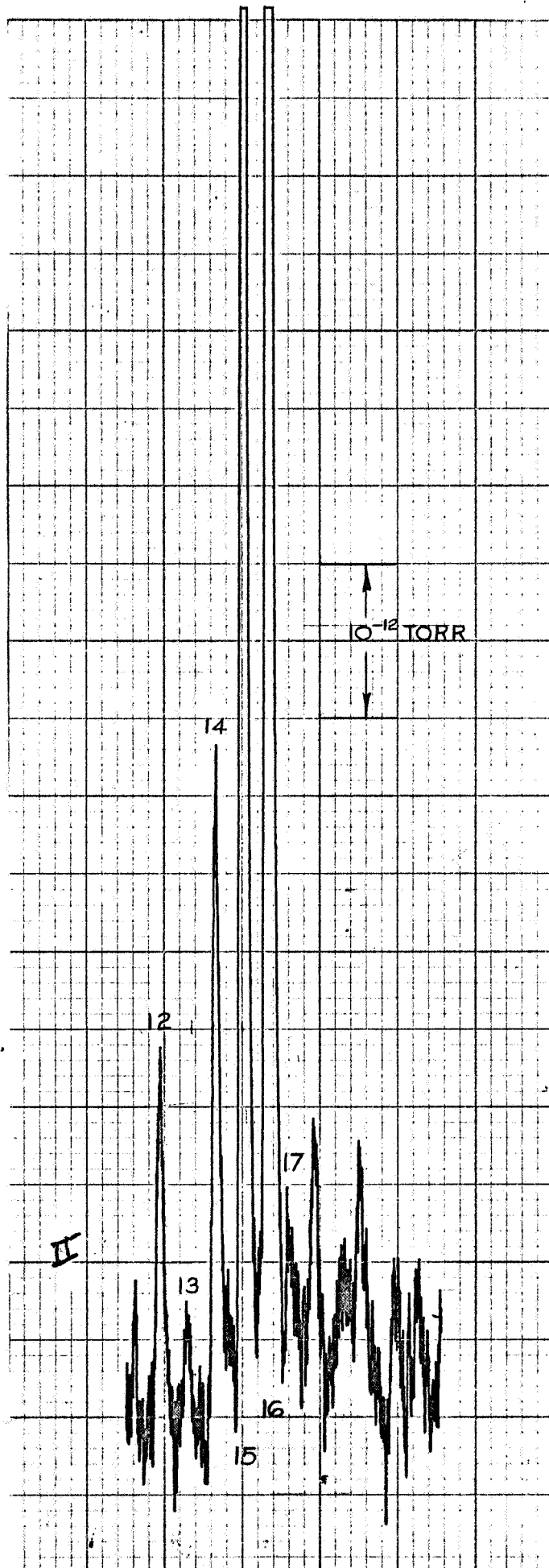
FIG. 18   T.O.F.   PARTIAL PRESSURE MEASUREMENT CAPABILITY

PARENT PEAK
HEPTANE (C₇H₁₆)
100
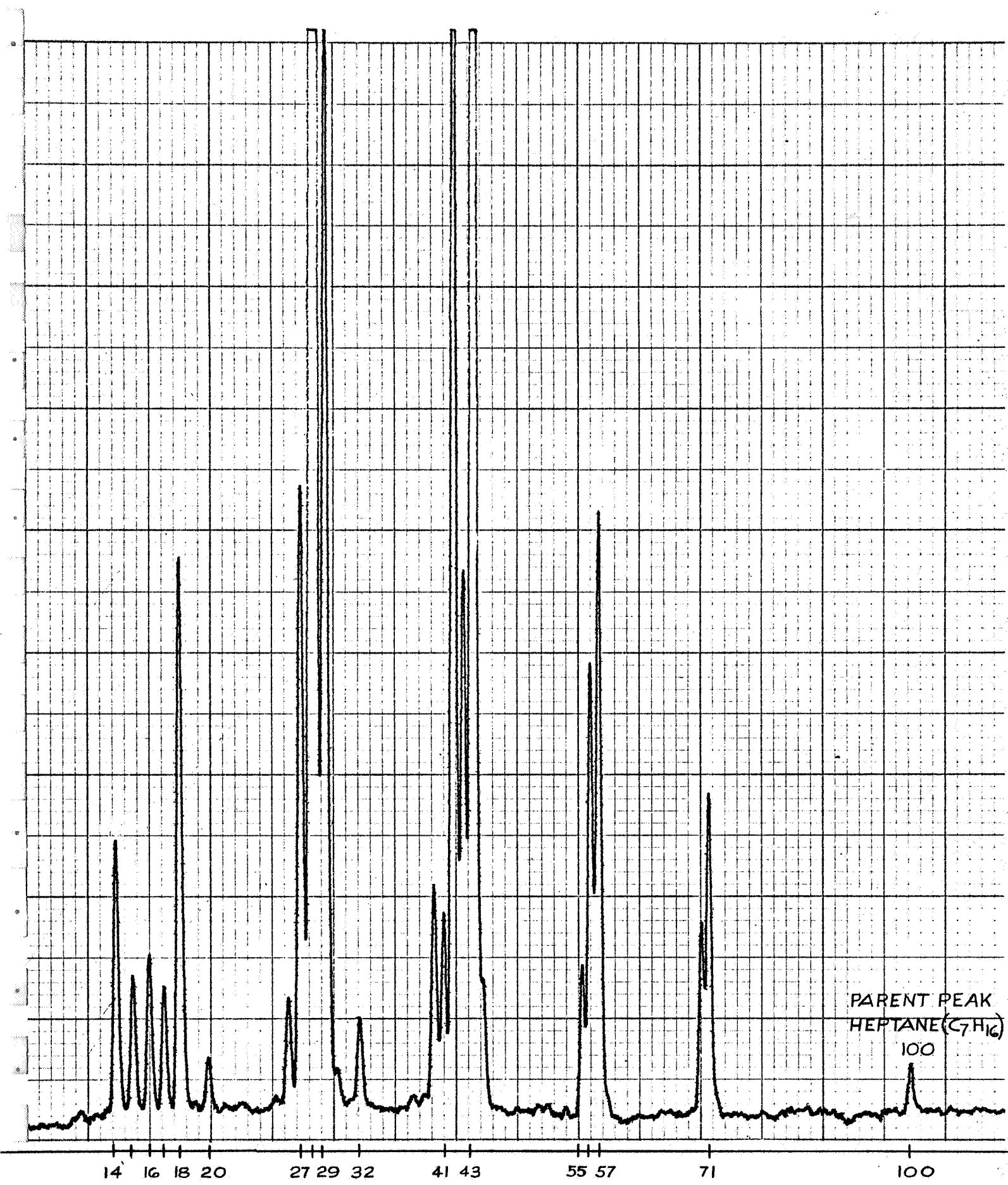
FIG. 19

T.O.F. SPECTRA OF RESIDUAL GAS PLUS SAMPLE - HEPTANE (C₇H₁₆)

10^{-10}TORR
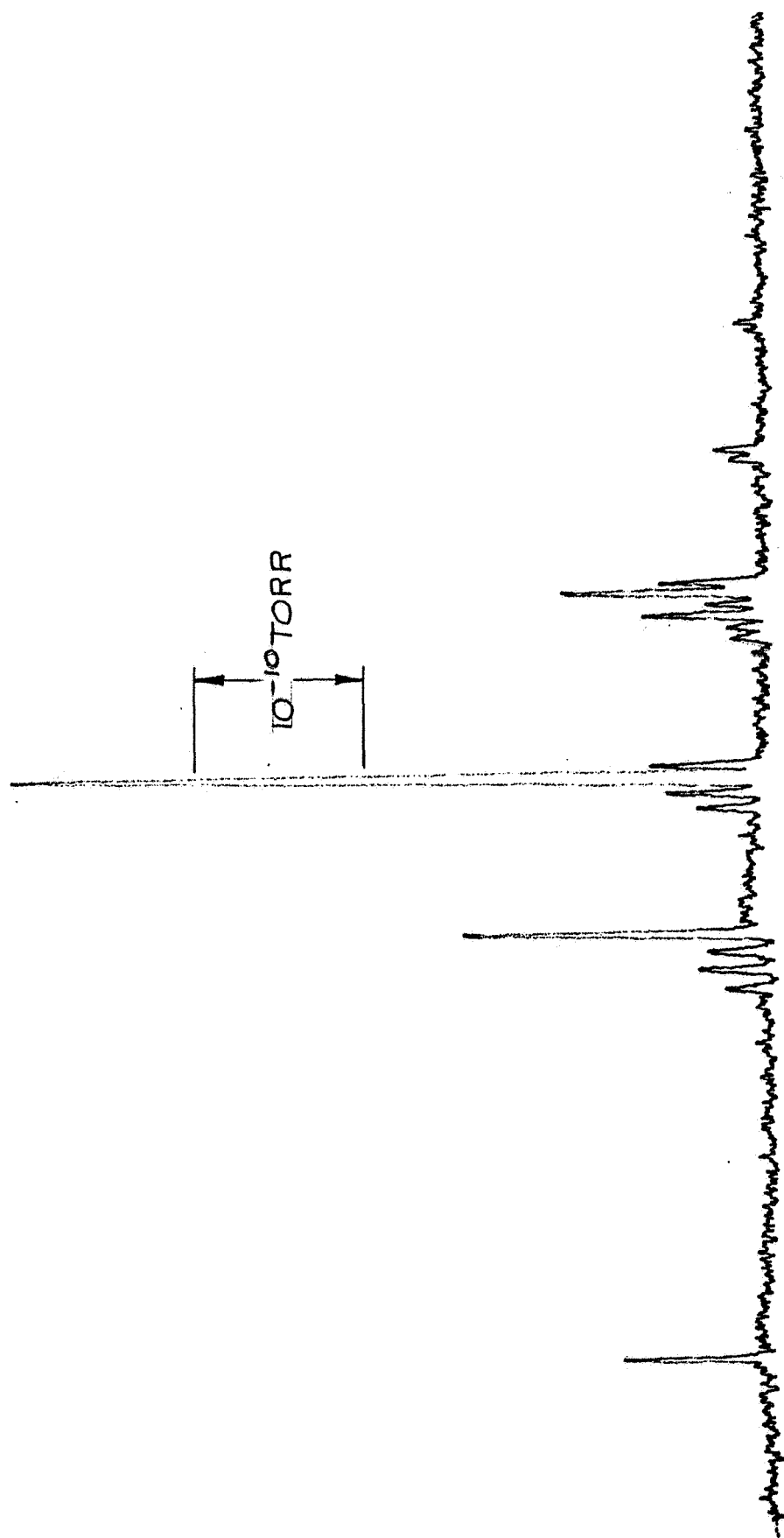
FIG. 20

T.O.F. SPECTRA AT REDUCED SCAN TIME

ION ENERGY 200 VOLTS

S/N in db
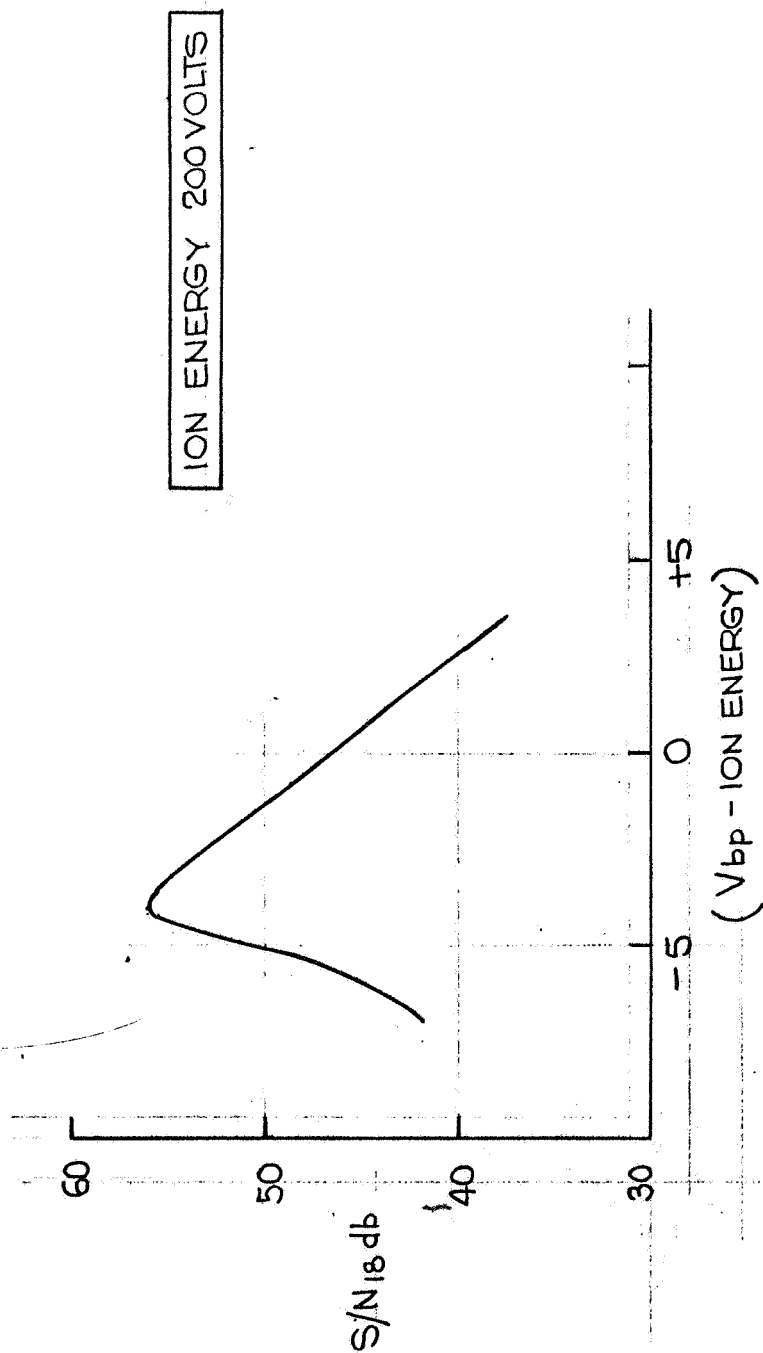
FIG. 21a

SIGNAL TO NOISE RATIO VS. DIFFERENCE BETWEEN BARRIER POTENTIAL AND ION ENERGY

$(V_{bp} - ION ENERGY)$

ION ENERGY = 150 VOLTS

$(V_{bp} - \text{ION ENERGY})$

FIG. 21b

— SIGNAL TO NOISE RATIO VS. DIFFERENCE BETWEEN BARRIER POTENTIAL AND ION ENERGY

2.   The optimum setting of V_{BP} is also a function of the ion energy. The narrow-shaped S/N curve is not desirable from the standpoint of effects due to long term drift. Furthermore the absolute value of S/N at the optimum V_{BP} is less for the higher ion energy levels. On the basis of these observations the 150 volt ion energy level was finally selected.
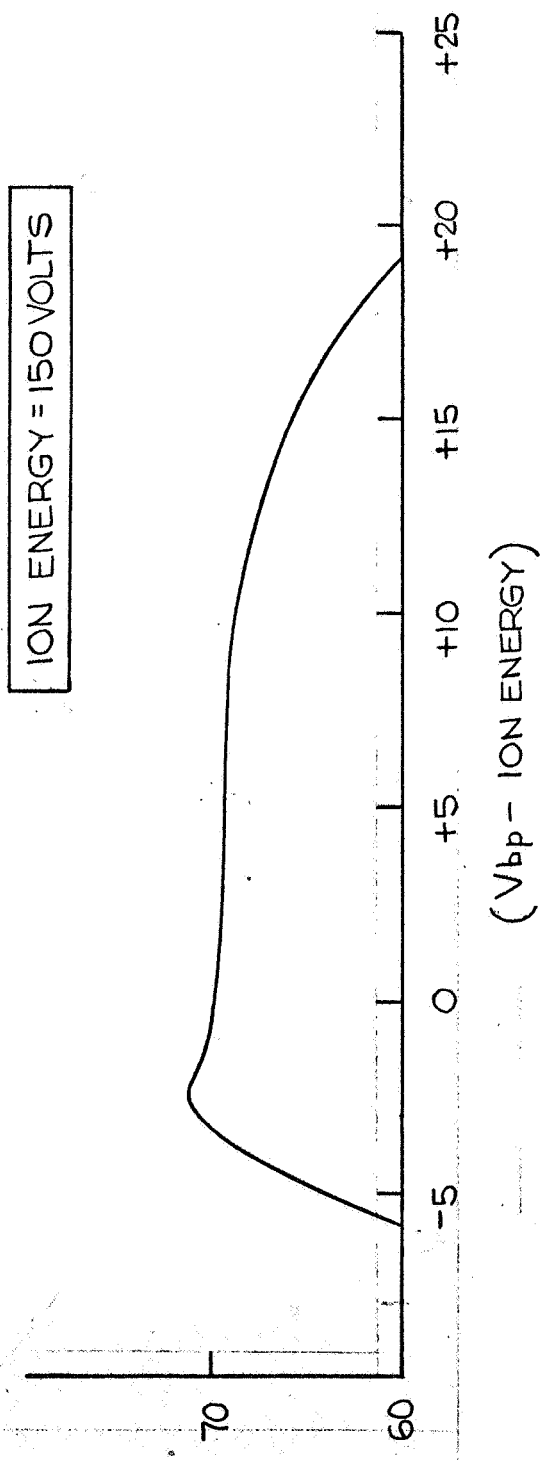
(Note: S/N ratios were computed using the peak to peak noise and the height of the largest peak in the spectrum.)

The effect of sensitivity on ISP repetition rate is graphically illustrated in Fig. 22. At the same time, note that length of the flight path will limit the maximum rate (i.e., that at which succeeding spectra will begin to "overlap"). In any event it is optimum to select the fastest rate determined by the flight time of the heaviest mass present in the spectrum. For mass 250, 200 volt ion energy, and a flight path of 60 inches, the maximum rate is calculated to be 8.3 kc. An ISP rate of 5 KHz was selected to allow adequate time between spectra for various circuits to reset and stabilize.

DISCUSSION

The resolution of a TOF mass spectrometer deteriorates if there is a significant energy spread in the ion beam being analyzed. For example, an energy spread of $\pm$ 0.5 volts (S.D.) would begin to cause difficulty if a resolution of 100 was desired and ion acceleration was 150 volts.

Little is known about the distribution of energies of the lunar atmospheric constituents at various heights above the surface; however, it is clear that during the lunar day their "temperatures" will range up to at least 400°K, from solar heating, to perhaps 4×10^{6} $^{\circ}$K, the higher temperature being due to interactions with, for example, solar wind protons. If it is assumed that all, or at least the vast majority, of neutral particles in the lunar atmosphere close to the lunar surface have approximately the same temperature as the lunar surface, then the mean temperature of the lunar atmosphere in this region will be not greater than about 400°K above the lunar surface but the exact form of this temperature increase is presently not known. A molecule must have a mean "temperature" of above $30,000^{\circ}$K, equivalent to 3 volts, and be moving essentially parallel to axis of the analyzer to cause the performance of this TOF mass spectrometer to begin to deteriorate. It would seem that substantial concentrations of such particles will not be reached within several hundred kilometers above the lunar surface, if indeed they are reached at all, since such "temperatures" imply velocities sufficient to cause the complete ejection of the particles posessing them from the Moon's atmosphere, if directed upward. The reasoning given above is based in part on considerations of energy absorption in the earth's atmosphere at a height where the pressure is approximately equal to that believed to be present near the surface of the moon (Refs. 25, 26, 27). It seems likely, therefore, that the range over which a lunar-surface-based TOF mass spectrometer could analyze the neutral lunar atmosphere will not be limited by the temperature distribution of the constituent particles, but rather by the detection sensitivity of the apparatus.
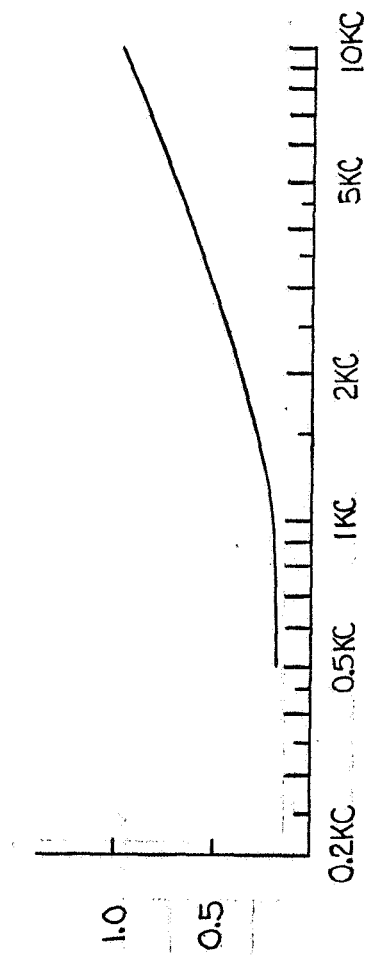
FIG. 22

SENSITIVITY VS. ION SOURCE PULSE REPETITION RATE

The situation is of course considerably worse when one considers studying the ionized constituents of the atmosphere as many of these are expected to have substantial energies, ranging in fact up to the energies of solar wind particles, even the MeV energies of cosmic ray primaries. Obviously it will not be possible to study the most energetic of these ions with any "flyable" mass spectrometer, even if "double focusing;" besides, other techniques (e.g. semiconductor-impact detectors are available for this. Ions of moderate energy(e.g. up to say 100 volts) can be handled by double-focusing magnetic spectrometers, or, to some extent, by "mass filters" (monopole, quadrupole) — if they enter the analyzer moving near-axially. But a TOF such as that described herein can also analyze ions with appreciable energy (up to say 10 eV) if they are moving perpendicularly to the axis of the analyzer. For analyzing neutrals, an "ion trap" can be used to remove ions in the atmosphere so that they do not blur the spectrum.

It is clear that any lunar atmosphere considered will be partically ionized by charge exchange with the solar wind and photoionization by ultraviolet radiation from the sun, the former mechanism being probably the more important of the two. Several workers (Refs. 28., 29.) have calculated the degree of ionization and estimates vary from 10^{-2} to 10^{-4} for the atmosphere as a whole. The only measurements on the lunar atmosphere which give an indication of the number of ionized particles present, however, were those of Elsmore (Ref. 2.). His measurements indicated an electron density of 10^3 cm^{-3} and he derived an ion density relative to that of the particle density equal to 10^{-3}.

Bernstein et al. (Ref. 29.) have predicted that all ionized particles in the lunar atmosphere will be singly charged. This seems rather unlikely, however, as the energy of solar wind protons is 470 eV (assuming a wind velocity of 3 x 10^7 cm/sec) and the photon energy of, for example, the strong He II 304 solar ultraviolet emission lines is 40 eV. Since the second ionization potentials of many elements likely to be found in the lunar atmosphere range from 25-40 eV, it is clear that multiply charged ions may be found, which might considerably complicate the spectra obtained.

An advantage of the TOF over most other types of mass spectrometers is its ability to produce many spectra per unit time. It is difficult to capitalize on this feature for stationary-site lunar atmosphere analysis as the operating pressure is so small. On the other hand it is most useful in a probe moving through an atmosphere. However, data handling equipment of an impractically high signal bandwidth would be required to monitor individual spectra. To overcome these problems, the gated ion detector was developed, allowing ions of a given mass to be added over several spectra, whereby an output spectrum is obtained showing considerable signal-to-noise improvement. At a total pressure of 7 x 10^{-10} torr, partial pressures as small as 8 x 10^{-13} torr were clearly distinguishable while the noise was on the order of 2 x 10^{-13} torr. As this "noise" is in part pressure dependent, it is reasonable to expect that at the reduced pressures expected on the lunar surface, partial pressures as small as 10^{-13} torr will be measurable. Recent tests with the breadboard TOF showed a resolution of 60 at a measured sensitivity of 5 x 10^{-3} ion amp/torr. While the present source to detector spacing is 20", the proposed final spacing is 60", which could as much as triple the resolution. Because of the large cross section

of the ion beam (ca. 1") the vertical alignment of the source and detector is not very critical, while parallelism of source and detector grids is more important, to achieve the resolution figures used herein, only rather easily achievable alignment is required. Little or no sacrifice in sensitivity would be experienced if the flight path was increased to 60". For reasons explained earlier, the ISP repetition, limited to 8KHz by the 60" length, has been selected as 5KHz to avoid the possibility of overlapping spectra or insufficient recovery time for the control electronics.

Although this TOF was originally chosen and designed for in-flight lunar atmosphere analysis, it is certainly suitable for atmosphere analysis performed on the lunar surface as part of either a manned or unmanned mission. A manned mission offers at least two advantages over either an unmanned landing or crashing mission. First, the apparatus could be carried some distance from the lander, thus reducing vehicle outgassing contamination problems. In addition, the astronaut, by setting-up the TOF with a considerably greater source to detector spacing than is practicable on either an unmanned lander or atmosphere-transiting vehicle could increase the resolution of the instrument substantially over that which could be obtained in the confined of a vehicle, with no weight increase. (This is only true for a TOF spectrometer.)

In contrast, however, a consequence of performing the lunar atmosphere analysis experiment on the lunar surface rather than during passage of the apparatus through the atmosphere is that no information about the variation of the atmospheric composition with altitude can be obtained. It is true that the sensitivity requirements of the spectrometer become more severe at increasing distances above the lunar surface, however the decreasing atmospheric density with altitude is compensated for to some extent, by a "ram effect" due to the motion of the spectrometer through the atmosphere. During the final stages of a flight to the Moon, the analyzer would be moving faster than the thermal velocity of most of the particles in the lunar atmosphere. Thus, if the analyzer were mounted at the front of the vehicle, the source pressure would be higher than the total ambient pressure and this increase might be as much as an order of magnitude. The "ram effect" is mass dependent, as the magnitude of the effect is determined by the analyzer velocity relative to the molecular thermal velocity, and this, in an isothermal atmospheric layer, is inversely proportional to the square root of the mass of a molecular or atomic species.

For in-flight analysis of the lunar atmosphere the "ram effect" would be helpful, as it would be for the in-flight analysis of the outer layers of planets with more dense atmospheres such as Mars, Jupiter, Venus, and the Earth. As the surfaces of these planets are approached, however, the analyzer pressure will rise until the instrument becomes inoperative due to filament burn-out, or when the mean-free-path of ions in the analyzer begins to approach 1% of the ion flight path distance in the TOF. In this case, the "ram effect" increases the height above the planetary surface at which this failure occurs. (Provision of a vacuum pump of course can reduce it substantially.)

The mass spectrometer promises to be a powerful tool for planetary atmosphere analysis either performed on the surface of the planets or during passage of the analyzer through their atmospheres. As the initial missions to planets beyond

the moon are likely to use either crashing or orbiting vehicles, analysis of their atmospheres will have to be performed in flight. It is our belief that a TOF mass spectrometer of the type presently being developed for lunar atmosphere analysis could, with suitable modifications, be used to determine the composition of these atmospheres. Pumps would be used to extend the range in the atmosphere over which the spectrometer could operate, and, in atmospheres denser than that of the Moon, advantage could be taken of the rapid analysis rate of the TOF.

As was mentioned above, if the lunar atmosphere analysis experiment was performed on the lunar surface, it would be desirable to set up the experiment at some distance from the lunar lander in order to minimize vehicle outgassing contamination effects. Placing the experiment on the lunar surface outside the lander requires that the apparatus be designed to operate in the hostile temperatures and radiation environment of the moon. Temperature control must be provided to maintain the equipment temperature within somewhat smaller temperature limits than the extremes of $150^{\circ}K$ and $400^{\circ}K$ attained by the lunar surface in a night and day cycle. The incidence of particles such as solar wind protons and various forms of radiation—gamma, x-ray, U.V., etc. and any radioactivity arising from the lunar surface layer can contribute to a serious noise problem – especially as an electron multiplier is mandatory to satisfy the high sensitivity requirements of the apparatus. This noise level will not be constant but will fluctuate with solar activity and with the passage of the apparatus from day into night, the noise level being highest during the daytime and smallest during the night when the bulk of the moon will shield the experiment from the solar wind and solar radiation. We have discussed these problems in earlier reports (Ref.17).

RECOMMENDATIONS FOR FUTURE WORK

As the above report indicates, this development program has now reached a point where an apparatus exists in the laboratory which meets the criteria set for an in-flight lunar atmosphere analyzer, the original goal of this program.

In the meantime however changes in direction in the space program have, apparently, ruled out such a mission in favor of performing lunar atmosphere analysis as part of the manned lunar exploration program. The instrument as it stands is at least adequate for this service and in fact the Astronaut can enhance the instrument's capabilities significantly by setting up the instrument in an optimum orientation not possible by an unmanned mission.

Given an immediate go-ahead, the present laboratory device could be "hardened" into a satisfactory final configuration without difficulty.

At the same time, there are obvious areas in which additional work could produce improvements. Some of these are as follows:

1. Incorporate provision in the electronics for remote measurement and/or control of important parameters to permit optimization of performance, to facilitate trouble-shooting, to compensate for similar changes in performance, etc.

2. Construct a version with a "coincidence" circuit and test its capabilities vs the non-coincidence TOF, in various environments of interest — i.e. at total P from 10^{-8} to 10^{-12} torr, in strong "cosmic ray" flux, etc. (An existing coincidence TOF built under NASA sponsorship by another contractor is laboratory scale; however, a part of the technology developed in applicable.)

3. Investigate performance as a function of source to collector drift-space spacings.

4. Perform long-period runs to simulate long-duration analyses made by a TOF left behind on Moon by Astronauts. Confirm that if long-term accelerating voltage drift is kept less than 100 ppm, length of time taken for analysis is immaterial.

5. Investigate performance when ions make up an appreciable proportion of the gas to be analyzed.

6. Investigate whether the device as it now exists is a superior starting point for a light, portable instrument for applications such as

   a. monitoring toxic constituents of confined atmospheres (spacecraft, submarines, etc.)

   b. unmanned probe atmospheric composition studies of planets

   c. detection of chemical (gas) warfare agents

d.   monitoring performance of internal combustion engines (exhaust studies)

e.   monitoring oxygen content of blood via breath-by-breath analysis; patient monitoring in hospitals, etc.

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